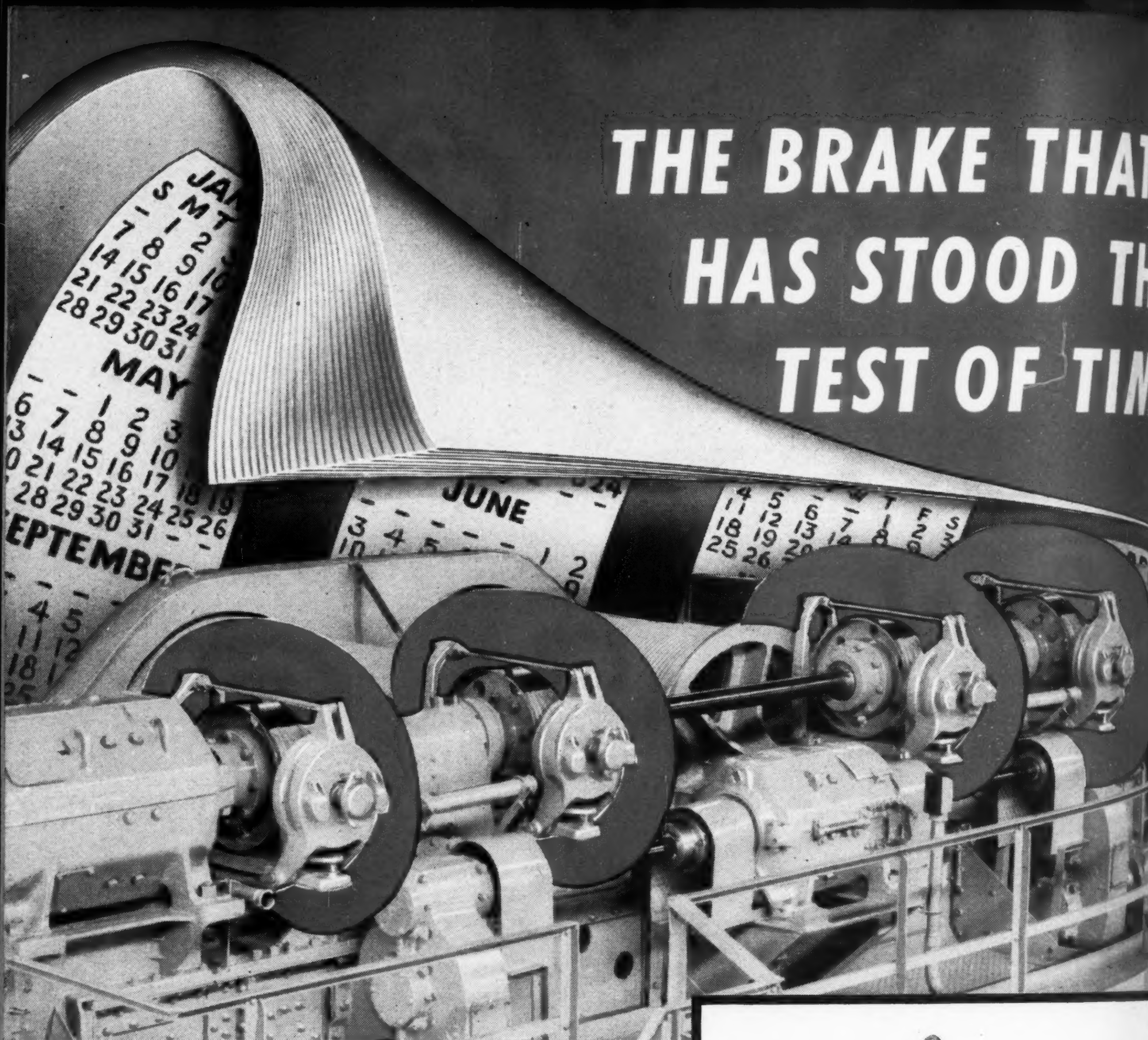
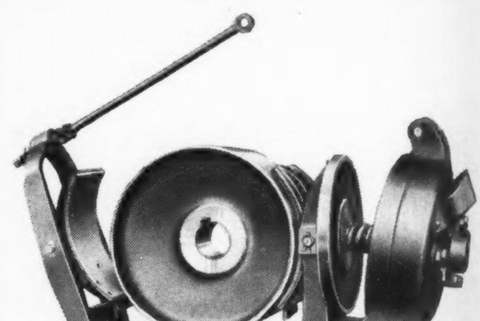
MACHINE DESIGN

October 1945

Featuring DESIGN MATERIALS



Cutler-Hammer engineers, long versed in mill requirements, designed the C-H Type M Brake with those specific needs in mind. With braking essentials concentrated into a few rugged parts, the C-H Type M Brake is simplicity itself; yet endowed with all the durability demanded by heavy duty operations. So dependable and efficient has been its performance that the C-H Type M Brake has never relinquished its preferred position anywhere. This matchless record is but another tribute to the engineering skill that has made the name Cutler-Hammer world-famous ... another reason why discriminating users of electrical equipment today insist on Cutler-Hammer Brakes for each and every heavy duty installation. CUTLER-HAMMER, Inc., 1310 St. Paul Ave., Milwaukee 1, Wisconsin. Associate: Canadian Cutler-Hammer, Ltd., Toronto, Ont.



Power transmitted in a straight line is power at its greatest efficiency

Exploded view of C-H Type M Magnetic Brake shows simplicity of design, ruggedness of parts and directness of power application.

CUTLER·HAMMER
MOTOR CONTROL
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Topics

ONE GRAM of radium compound, containing enough pure radium to cover a pin head, is all that is needed to illuminate several dozen aircraft dials with a never-failing glow at a cost of about $25.

WEATHER FORECASTING has been added to the score of services supplied the American public by radar. In operation since last August, a specially equipped bomber has supplied prompt and accurate weather reconnaissance. With his set trained on the air, the operator can track clouds to indicate approaching storms.

INTERNAL - COMBUSTION ENGINES being designed by Allis-Chalmers will use alcohol as fuel. These engines are intended for export to countries where gasoline is prohibitively expensive and where alcohol can be made cheaply from organic materials readily at hand.

SEMICONDUCTORS made of metallic oxides which are pressed into disks, extruded into rods or formed into tiny beads have been developed by Western Electric Co. These small circuit elements, having negative temperature coefficients of resistance, may have coefficients as great as 5 per cent per degree Centigrade.

DIRECT FUEL INJECTION systems shooting pressurized sprays of fuel directly into B-29 engine cylinders supplied the needed getaway power for the two Super-Fortresses which dropped atomic bombs on Hiroshima and Nagasaki.

NETWORK OF EIGHT PLANES flying at an altitude of six miles will provide television and FM broadcasts, covering the nation from coast to coast. The system will be inaugurated, according to Westinghouse engineers, just as soon as permits and equipment can be obtained. Programs originating in ground stations will be beamed to the cruising planes, then rebroadcast to television receiving sets. Each plane will be capable of broadcasting to an area 422 miles across, thus cracking one of the toughest nuts in television broadcasting because a ground transmitter covers a radius of only 50 miles. At that point the waves travelling in a straight line, leave the earth. One kilowatt of power from a plane will cover its area whereas fifty kilowatts would be needed by a ground station to cover its smaller restricted zone.

SUPER-CUTTING ALLOY, developed by the Germans during the war, requires no tungsten. It consists essentially of vanadium and titanium carbides bonded with metallic nickel.

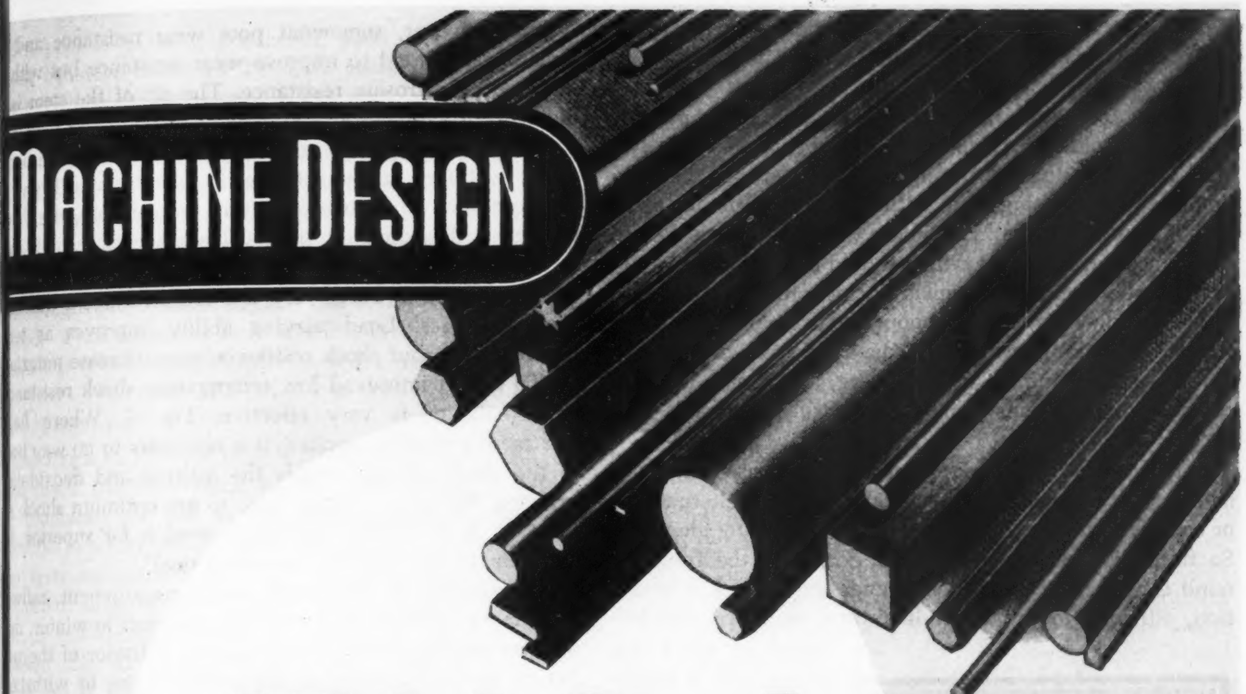
VACUUM-PACKED 36-volt storage batteries used in balloon-type weather forecasters retain their charge indefinitely until used.

HARD WALLBOARD made from sawdust and other wood waste would provide enough construction materials for 1,000,000 houses annually without cutting one additional tree. A simple method for producing this new material has been developed by Dr. Othmer at the Polytechnic Institute of Brooklyn.

ZIRCON PORCELAIN type of ceramic insulation has been developed by Westinghouse for use with ultra high frequency equipment. It has better electrical and mechanical properties than previously available materials.

FASTER—with respect to initial rate of climb—than jet-propulsion aircraft, Goodyear's F2G climbs at 7000 feet a minute. Maximum speed is 450 miles an hour with water injection. The plane has Pratt and Whitney's new 28-cylinder Wasp engine developing more than 3650 combat horsepower, driving a four-bladed propeller.

GLOW LAMPS, miniature fluorescent lamps about the size of an average marble, provide more light than a quarter-watt neon lamp with an energy input that does not add up to one kilowatt hour in a year's continuous burning.



Which Steel Shall I Use?

By H. W. Gillett
Technical Adviser
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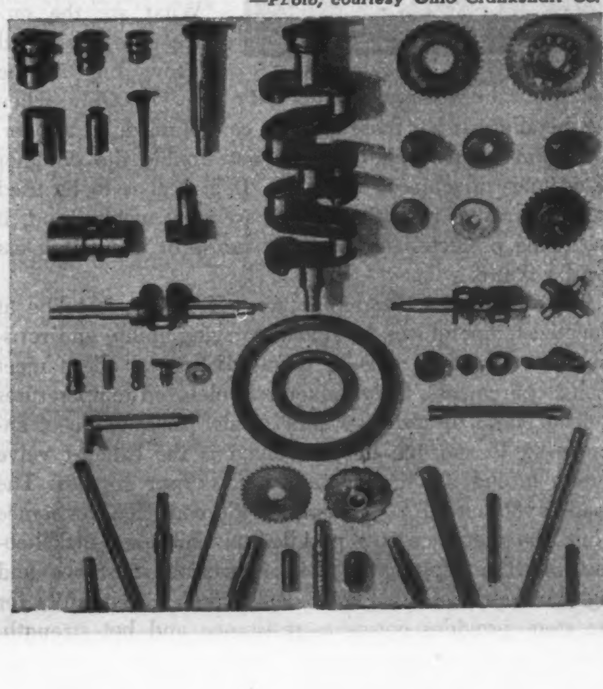
STEEL can be concocted and heat-treated or cold-worked to have a static load-carrying capacity anywhere between 20,000 and 200,000 pounds per square inch with toughness, varying inversely to strength, to an equal degree. There are size limitations to achieving both strength and toughness. To overcome these limitations as far as possible is the main purpose of adding alloying elements to steel. Within the size limitations, as extended by intelligent use of alloys, the particular choice of type of steel and the heat-treatment to be applied are dependent on whatever the designer demands as the optimum compromise between strength, toughness, hardness (*Fig.* 1), etc.

Because he realizes, consciously or subconsciously, that other attributes count beside those recorded in handbooks or determined by routine mechanical testing, the average designer is a bit hesitant to change his specifications to permit an alternative steel or treatment. He has a lurking fear that some hidden factor in a new material may make it unfit for his application.

Yet, from some quirk of psychology, when necessity demands a substitution, the average designer's first thought is to look in a handbook for a list of acceptable substitutes instead of talking the matter over with a

Fig. 1—Induction hardened machine parts. Hardness characteristics are carefully controlled and may be confined to any local area requiring wear resistance
—*Photo, courtesy Ohio Crankshaft Co.*



metallurgist. Unfortunately, the handbook can't ask questions but the metallurgists can and do ask pertinent questions.

Certain data sheets, lists and even slide rules purport to tell what older SAE steel may be substituted by an NE steel. They may be right, sometimes they are, or they can be dead wrong. Using them without consideration of other data is an unintelligent, lazy man's way of avoiding the use of engineering judgment which should be based on evaluation of true needs and availability of what will fill those needs. We know no one wise enough to make up a useful list without appending an encyclopedia-sized series of footnotes modifying and limiting, or expanding, as the case may be, the general statements to make them truly applicable to a specific case.

Yet, with an understanding of a specific case, any good metallurgist can find one or several acceptable alternatives, or can give sound reasons for the absence of any alternate. So from here on, this article will deal with the frame of mind in which the machine designer should seek information, either from published literature, or, more expeditiously, by sitting down with a metallurgist to answer, as well as to ask, questions.

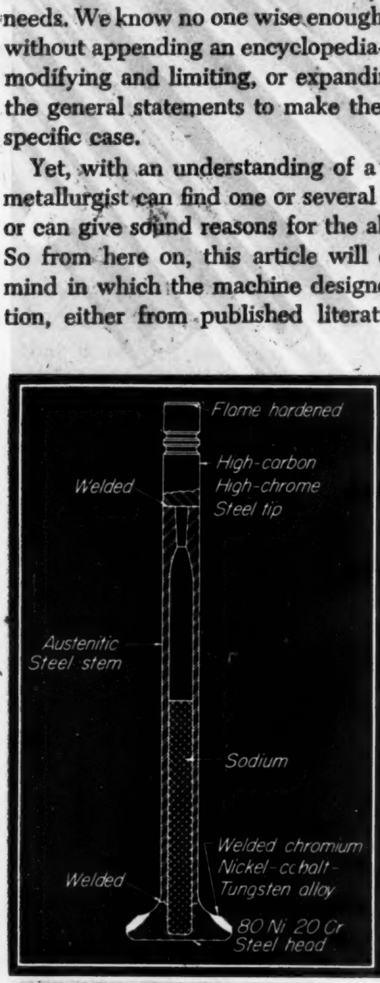


Fig. 2 — Exhaust valve for high temperature service illustrates how materials may be combined to produce desired properties at critical locations

When the designer asks, "What steel shall I use?" the metallurgist asks, "What are the service demands?" and "How big is the piece?" Only when the metallurgist has those answers can he make his answer.

Certain service conditions do not trouble the designer of ordinary machines, others do. If a steel is to be used under corrosive conditions that bare steel won't stand, it has to be protected unless the expense of using stainless can be borne.

High and Low Temperatures: If service is to be at elevated temperatures, both load-carrying ability and resistance to oxidation may be required. Special alloys meet such requirements. Only moderately elevated temperatures can be borne by ordinary alloy steels. An example of engineering to suit the duty involved is the exhaust valve shown in *Fig.* 2 for extremely high-output engines. The head is 80 nickel 20 chromium for corrosion resistance while the seat face is a puddled-on chromium-nickel-cobalt-tungsten alloy having high corrosion resistance and high hot hardness. Austenitic steel (15 Cr 15 Ni 2 W) for the stem provides corrosion resistance and hot strength. It has, however, somewhat poor wear resistance and is sometimes nitrided to improve wear resistance but with sacrifice of corrosion resistance. The tip of the stem is high-carbon high-chromium steel (1.25 C 12 Cr) with f… corrosion resistance and good wear resistance. Flame hardening is utilized on the extreme tip to resist wear from the valve rocker. To reduce operating temperature, the valve is filled with sodium. A solid valve made of a single material would fail rapidly.

If service is to be at very low temperature, a different problem arises. Load-carrying ability improves as temperature falls, but shock resistance may decrease amazingly. To obtain improved low temperature shock resistance, heat-treatment is very effective, *Fig.* 3. Where heat-treatment cannot be applied, it is necessary to go way back to the steel mill and juggle the melting and deoxidation practice, the type of ingot, etc., to get optimum shock resistance. A fully-killed, fine-grain steel is far superior, for such use, to run-of-mine "structural steel".

The designer of bulldozers, logging equipment, railway equipment and like machines used outdoors in winter, may need to evaluate the low temperature behavior of the particular steel to be used if his machines are to withstand shocks at low temperature and if the parts subject to shock stresses contain notches or similar stress raisers. Avoidance of shock or avoidance of notches practically eliminates the danger but, if service involves the first and design cannot avoid the second, the problem is present.

The thing to remember about steel for such service is that no guarantee of low temperature shock resistance can be made without testing the particular heat of steel to be used unless the heat is pedigreed so that it is certain that melting, finishing and ingot practice are right. Even then it is wise to test, because in this particular respect, each heat is prone to show unpredictable individuality.

Section Size Influences Characteristics

Impact: The test usually applied for evaluating low-temperature shock resistance is the conventional notched-bar Charpy impact test, performed at the temperature of service, or better, over a range of temperatures above and below that temperature. Such tests tell something about the way the steel is going to break, i.e., whether with a tough or a brittle fracture under the influence of shock and a notch at that temperature *in the size tested.* The figures have no value for larger sizes because there is a very marked size effect. Tiny sections will act tough, large ones brittle for the same steel, even when the factors have been adjusted that tend to make large sections inferior in other ways to small ones. Size effect is a bit more obvious at low temperatures but exists equally at room temperature.

This is taken account of in crane hooks. Big solid ones may snap; those built up of many thin plates, bolted together, do not. Hence, built-up design should be kept in mind. When large sections must be used, there is no good substitute for an actual test on the actual piece, full size and conformation, not a scale model.

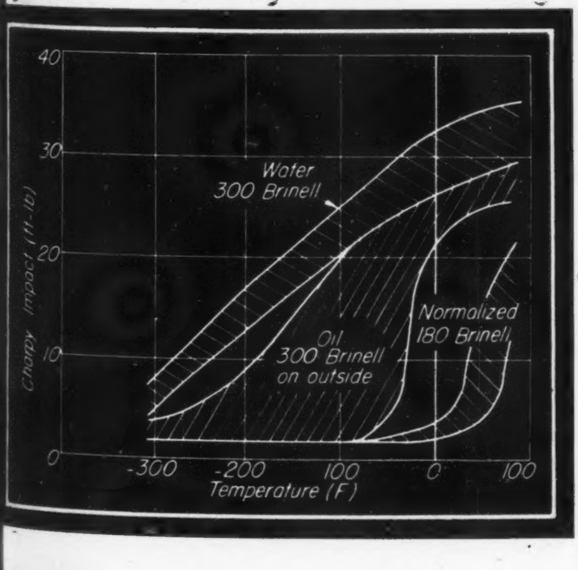
No broad reliance can be placed on anybody's say-so that some certain alloy steel has wonderful low-temperature behavior. In a laboratory test on a dinky little specimen from another heat or in another size, it may give results that are wonderful but not wonderfully good.

Irrespective of size, consistent good low-temperature ock behavior is shown by *fully austenitic* stainless or nganese steels, by copper alloys and indeed, by most nferrous alloys that are decently shock resistant at room nperature. It is the everyday steels that are black sheep. Actually, the *required* shock resistance and toughness a part in service often must be very much less than is ought. A fine example of this is the very-close-to-brittle rd cast crankshaft. It was substituted for forgings on hich high notched-bar impact values formerly were reired. Ford designers took account of the fact that the nkshaft is not in shock service and eliminated this surfluous requirement after they had analyzed the condins of service.

Directional Properties: Many serviceable parts have en made from bar stock whose ductility and notched-r toughness are fine in the longitudinal direction, the ection in which reported tests are made. When toughss tests are made across the section, however, a huge oportion of bar stock will show itself so low in toughness at, if the designer knew it, he would be very much ocked, *Fig.* 4. Ordinarily he doesn't know it, uses the ck and it works fine in spite of the fact that service esses are not exclusively applied in the longitudinal dition only. Actually, little toughness is needed in most chine parts even though, concomitant with the yield ength the part must have, the steel may have high ghness and ability for huge plastic deformation. When ectional properties are required, a good thing to rember is that they are a result of rolling or forging. Steel tings, while generally less tough than wrought matel in its longitudinal direction, do not have such direcnal properties. Therefore castings can be a lot tougher the transverse direction.

Plastic Deformation: Ability to deform vastly rather an to snap may, in some parts, be required for accident urance. But, since operational failure ensues in most dern machinery under very slight permanent deforman, the designer carefully sees to it that such deforman is avoided. Ability for huge deformation is only required when true accident insurance is needed. If a part doesn't need such insurance or if it is protected by the toughness of another part that will give way before the first does, putting vast toughness into the steel is all poppycock.

7. 3—Impact characteristics of SAE 1045, normalized water or oil quenched and tempered at 900 F in 0.4 square section. Oil-quenched parts were slack quenched



Much poppycock has been spread about with respect to toughness of the core of carburized parts. If the case is ground off the "tough" core tested, it is tough all right but, if the case is left on and a crack is started in the case, that crack propagates through the core. The combination is brittle. Anyhow, how good is a cracked, carburized case? No designer plans to have the case crack.

Hard Surfaces: Instead of picking a soft, squashy steel for the core and building up a thick case on it, modern practice uses a much harder core and a case only as thick as is needed for wear resistance so that the core won't squash but will adequately support the thin case. Several types of hard cases can be used, such as that obtained from pack or gas carburizing, a mixed carbon-nitrogen case from gas cyaniding or liquid bath cyaniding, or a straight nitrided case. Straight nitriding nicely avoids distortion but is a lengthy operation and requires specially-alloyed nitriding steels. Also, induction or flame hardened skin may be produced upon a strong core of a steel of suitable composition without changing the composition of the surface. Choice of steel is somewhat dependent upon the process adopted, whether carburizing, cyaniding, surface hardening or case hardening by other methods.

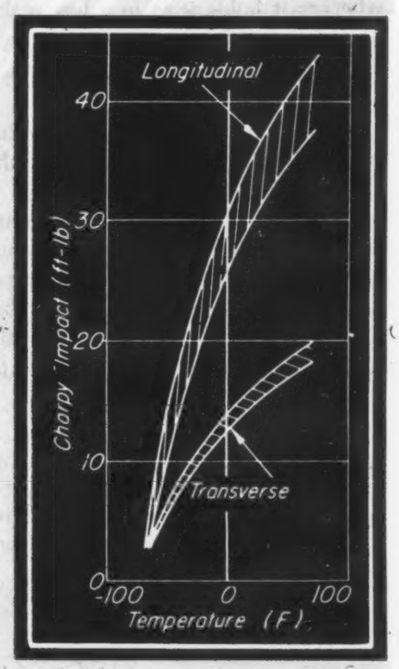


Fig. 4—Effect of temperature on impact values for SAE 1020 steel, ½-inch plate as rolled, 120 brinell

Other things being equal, the process chosen will depend on the size, shape and irregularity of the part and on the number of pieces to be processed. Instead of specifying a carburized SAE steel which may have been used in the past, analysis of the service and properties required of the case and core will generally show several better and cheaper alternatives. In many cases, distortion involved in the ordinary carburizing processes requires a heavier case and more grinding than are necessary when modified processes and steels adapted to them are used.

Wear: Hard surfaces are utilized when wear problems arise. If close dimensions are no object, if some battering can occur without harm and if the battering is severe enough to produce a work-hardened skin, the part may be

made to produce its own hard surface in service through the use of austenitic steel, usually manganese. Under pressure too light to work-harden them, the austenitics are not good for wear-resistance. Under heavy pressure, they only serve for "air fits" because they batter. For most machine parts the wear-resistant skin needs plenty of hard particles held in some sort of a matrix. Carburizing a low-carbon steel produces such a structure, so does cyaniding. Surface hardening of a fairly high-carbon steel also serves for this purpose.

One can go still further and introduce specially hard carbide particles differing from those in ordinary steels, as by employing a high-carbon high-chromium steel. The hard particles and their amount and distribution will be selected according to how willing one is to pay for grinding, what the surface is going to work against, if and how it is to be lubricated and, very importantly, whether grit will get in. In general, designing to avoid entrance of grit or providing to flush promptly with lubricant is worth a lot more than spending money for buying and processing super-hard materials. In bearings, whether the bearing engulfs grit and takes it out of contact with the shaft or whether it holds it as in a lap, makes a great deal of difference on shaft wear. Shaft finish is also a factor. With bearings that engulf grit and with a smoothly polished shaft, softer shafts will serve.

Gears: Some types of gears bring in, or seem to bring in, problems involving several of the features touched on in the foregoing, plus still others. Gears may fail from surface wear or teeth may break out, either under impact or fatigue. As to impact, directional differences in toughness are more often recognized in gears than in most other parts, so fiber directions are carefully noted. From the extensive studies of Almen and Boegehold, however, it turned out that the real factors are tooth contact and tooth

Fig. 5—These tractor sectors are normalized, then hardened after machining. The sector teeth only are hardened by selective hardening to prevent warping and hardening of the section which has toughness and high impact strength

—Photo, courtesy Ford Motor Co.

finish. The steel can be any one of a wide variety of the stresses are held down by a sufficiently rigid assem to prevent deflection not counted on by the designer. chief metallurgical aspects are ability to heat treat w out distortion, *Fig.* 5, (a matter governed partly by composition, partly by heat-treating technique) and ity to take a good finish. Other investigations show surface finish is vital. In fact, the tool wear in finish chining gears was found important. When the tool w rapidly, the last gears cut before redressing the tool torn and damaged surfaces and they did not last in servi The answer was to raise the sulphur content of the just beyond what old-time specifications would allow.

Fatigue: With anywhere near decent design, th are no static failures in machine parts. Failures co chiefly from wear or fatigue. Both are surface phenome Wear is combatted by hardness. Fatigue starts from so surface nucleus, some major or minor stress raiser, the harder the steel the more it is affected by stress rai By going to too hard a surface, ability to carry repea loads is reduced, *Fig.* 6. When a wear-resisting surface necessary, *Fig.* 7, no notches, scratches, tool marks, fillets or the like can be present. In the complete abse of stress raisers, the harder steels are stronger in fatig but complete absence is never attained.

Decarburization: A prevalent, often unsuspe

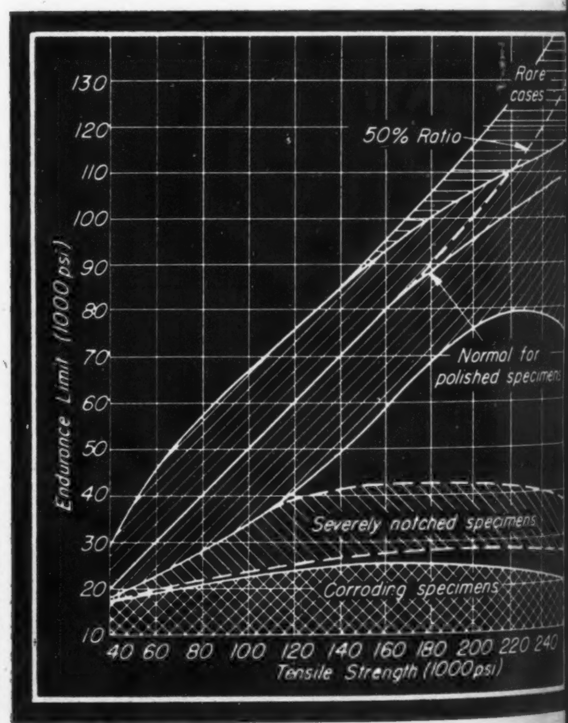


Fig. 6—Fatigue behavior of polished, notched and corr ing specimens of ordinary corrodible steels

cause of poor fatigue resistance lies in the presence weak, low-carbon, poorly hardenable surface layer ca by decarburization in heat treatment. This layer ca vulnerable yet so thin that it is not detectable under microscope, nor can its softness be revealed by ordin hardness tests. The layer and its effect are well re nized in springs where grinding well below any pos "decarb" is standard practice for severely stressed spri

There are many other parts, heat treated in their final ensions or merely lightly honed, in which unsuspected arb drops the fatigue resistance to a shockingly lower el than the same part would show if all decarb were oved. Any layer of decarb at all is thick enough for a ck to start, and a started crack propagates easily.

Whether pre-existence of decarb is a factor in fatigue of a machine part depends on whether it has or has not en removed. Steels vary in propensity toward decarb ording to composition. Commercially hot-worked car- or alloy steel has decarb, of that one may be sure. If mill surface has not been deeply removed in making part, some degree of decarb may remain. Decarb of erious nature may be produced in heat treatment but be largely avoided by use of controlled atmospheres. eed by using mildly carburizing atmosphere, some res- ation of surface carbon can be accomplished. Work dening the surface, as by shot peening, does miracles improving fatigue resistance, but it requires a reason- y strong surface to start with.

Stress Gradient Falls Sharply

INTERIOR PROPERTIES: Shifting from the surface to the erior, in heavy armor, for example, one is deeply con- ned with the properties of the interior. In service the nor may be deeply dented, i.e., subjected to material stic deformation. When a projectile is half-way through plate, maximum resistance to penetration is still needed much as at the surface. In most machine parts, the ditions are different, the center properties are not as portant.

The stress gradient in a machine part ordinarily falls off rply from surface to center. This is true even in a part ensibly loaded in pure tension, like a connecting rod. mewhere *on the surface* the local stress is always greater n calculated.

It is true that, if the yield strength beneath the surface is y much lower than at the surface, the stress gradient oss the section may be such that the weaker location eives higher stress than its yield strength, and hence stic deformation starts in some such subcutaneous loca- n. To guard against such deformation, it is desirable t the centers of large sections be reasonably strong, but practical cases they seldom need to be quite as strong the surface.

In large sections of heat-treated carbon steel, however, center is extremely soft. When the steel is quenched, center cools so slowly that only a thin rim at the sur- e is hardened. Water quenching is a bit drastic; it ors cracking of irregular objects. Oil quenching is less ble to cause cracking but it hardens less energetically, ing a still thinner hardened rim. The core transforms a structure much like that of ordinary hot-rolled steel. e surface hardens to the brittle structure called mar- site. Reheating martensite, i.e., tempering it, allows tening and toughening to any desired degree, such as yield strengths of 200,000 down to 100,000 pounds per are inch. Ability to do this tempering is what is sought quenching. Unless one gets martensite, he doesn't get t ability. There is only one way to beat the game, that to make the steel sluggish enough so that as it cools past transformation temperature the as-rolled structure is retained and is ready to change to martensite at a lower temperature.

MARTENSITIC HARDENING: Once martensite is obtained, the properties of the tempered structure produced from it are due to the carbon content. The alloy content does practically nothing, *Fig.* 8. The alloy content is there to make the steel sluggish. Sluggishness is needed only to quench fairly large specimens. If only hair springs for watches were made, there would be no need for alloy steels. However, for water quenching parts over ¾-in. diameter or oil quenching over ½-in. diameter, when center hardenability is necessary, alloy must be added.

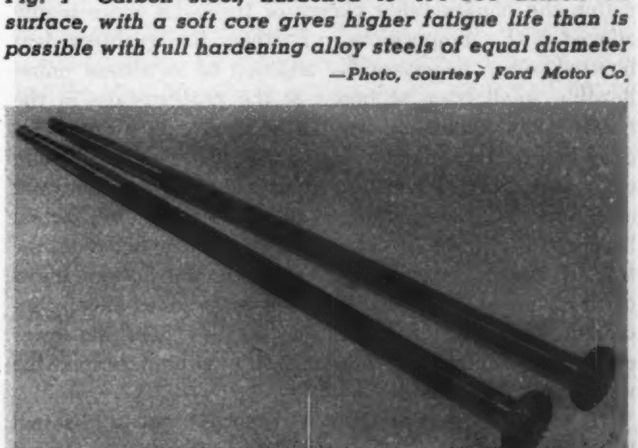
So many parts are made in larger sections, the center-hardening behavior is so touchy, and alloys are so expensive that a steel with just enough alloy for center hardening in just the section size needed is always sought. Old custom settled upon specific alloy steels for water hardening in certain sizes, others for oil hardening in still other sizes. Plenty of alternative compositions were known but manufacturing and stocking difficulties tended to keep the list down. Moreover, major differences in alloy content brought in the necessity for different temperatures for quenching and tempering. Once a steel was picked, the user tended to stay with it. Because of inevitable slight chemical differences in different heats and other unexplainable and uncontrollable differences, each heat of steel has an individuality of its own as to hardenability. Hence, in order to be sure that the least hardenable heat that will be met would have sufficient hardenability, a type composition was chosen that would have much higher average hardenability than was needed.

HARDENABILITY TESTING: The end-quench (Jominy) hardenability test directly evaluates the hardenability of a given heat of steel. The test can be made in the steel mill while the heat is molten and, if it is found to have low hardenability, corrective additions can be made. Present-day steels have much narrower bands enclosing the hardenability curves for different heats than of yore. They are still bands, however, not single curves, *Fig.* 9.

Understanding and control of hardenability plus the knowledge that any two steels that fully harden to martensite develop like properties on tempering (despite differences in composition) led to the realization that, for a given size section, any two steels with like hardenability

Fig. 7—Carbon steel, hardened to 477-555 Brinell on surface, with a soft core gives higher fatigue life than is possible with full hardening alloy steels of equal diameter

—Photo, courtesy Ford Motor Co.



curves and like quenched structures all through the section are interchangeable.

Conservation of Alloys: Scarcity of alloying elements here during the war, and in Germany long before the war, forced the avoidance of putting in a bit more alloy than the section demanded. This was possible through hardenability testing which makes it unnecessary to use a high-alloy level just to be on the safe side. The war also forced the use of whatever alloying elements were available and focused attention on those elements present in old alloy scrap produced before the days of shortages. Availability of new alloying elements was related somewhat to their normal cost and the profuseness or niggardliness of nature in providing deposits of ore. An exception was molybdenum, plentiful in the U. S. as low molybdenum-content ore, but costly per pound because of extraction costs from the ore. However, its potency is so great that only small, fractional percentages are needed.

The German answer to their conservation problem to make up for nickel, which they did not have, was to boost the chromium and the manganese, which they could still get. Their most important aircraft-engine parts, gun parts, and armor were shifted to a range of previously little-used, high-chromium compositions with hardenabilities adequate for the sections. As chromium became tighter, they cut the chromium a bit and boosted the manganese. The steels were perfectly adequate and entirely substitutable for the other steels of like hardenability.

The Japs, not beset by material shortages, used alloys lavishly, often copying prewar compositions rich in alloys. Especially in many gun parts they showed a predilection for steels quite high in tungsten, having the needed hardenability but seldom used for such purposes by Occidentals. These steels, too, are perfectly usable.

The American answer was based on the nickel and chromium content of alloy scrap, on the availability of molybdenum and on the knowledge that a moderate total made up of small amounts of several different hardenability-conferring elements is as effective as a much larger total made up of only one or two. Thus, the triple-alloy National Emergency steels came into being, the nickel and part of the chromium coming from scrap. Manganese and molybdenum were added as needed.

Boron-Treated Steels Improve Hardenability

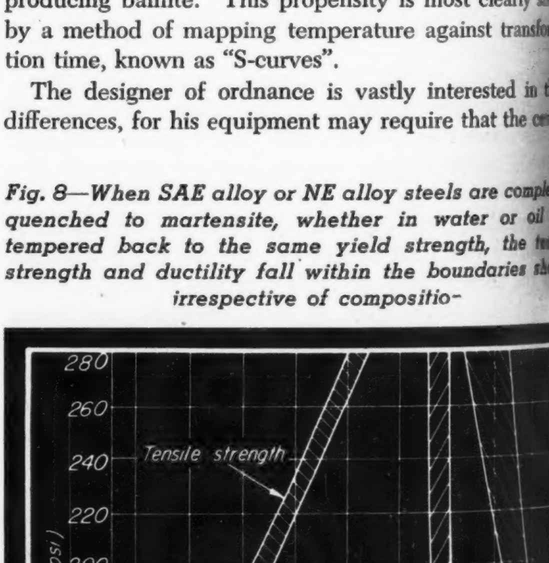
These were made at several levels of hardenability, to match the hardenability curves of the older more highly alloyed SAE compositions. Further, hardenability was boosted, when necessary, by addition of an almost unbelievably small trace of boron at the proper stage in the heat. About 0.003% boosts the hardenability as much as does half a per cent of some of the other potent alloying elements. These boron-treated or "needled" steels are not easily spotted by ordinary chemical analysis, but actual hardenability tests reveal a vast difference between the treated and untreated steel. The top and bottom limits of the band in *Fig.* 9 could be taken as schematically indicating the effect of needling a low alloy steel, the lower curve representing the hardenability without boron, the upper with boron added.

Hardenability Criterion: In other words, the real basis for comparison of wartime steels for heat-treatment was no longer the chemical composition but the hardenability. In essence, use was based on hardenability specifications even though composition ranges and NE numbers were assigned. The next step would be to forget all about alloy composition for steels to be hardened and call for a steel solely on its carbon level and its hardenability. For sections that will harden to 100% martensite, this comes close to being the correct and logical step. When the center of the section, however, does not harden to 100% martensite, the situation needs examination. There is a joker in the phrase which stated that steels were equivalent and substitutable when the hardenability curves and the structures across the section were alike. Hardenability curves can be much alike with the structure being the same, once past the position where the quenched structure is all martensite. Many alloy steels, quenched so that the interior cools at a rate just too slow to produce martensite, transform to another hard structure called bainite. The end-quench hardenability curve is insensitive in indicating just the depth to which martensite is produced and where bainite begins.

Metallurgists have generally considered that a quenched structure in which the center is only 50% martensite with the balance bainite is "fully hardened". The hardenability curve alone doesn't even tell the position at which such structure is reached. These allegedly "fully hardened" but partly bainitic centers do not temper back to as strong a product as does pure martensite nor is the toughness as good. Different alloy steels differ in propensity toward producing bainite. This propensity is most clearly shown by a method of mapping temperature against transformation time, known as "S-curves".

The designer of ordnance is vastly interested in these differences, for his equipment may require that the center

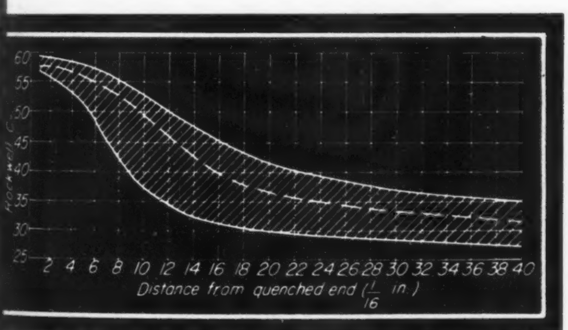
Fig. 8—When SAE alloy or NE alloy steels are completely quenched to martensite, whether in water or oil and tempered back to the same yield strength, the tensile strength and ductility fall within the boundaries shown irrespective of compositio-



nch to 100% martensite. The designer of peacetime hines is seldom much interested for the centers of his s are usually adequate at the somewhat lowered ngth and toughness level, in which case the mere like- of the hardenability curves may be adequate without rying about differences of structure in the transition e where pure martensite grades off into bainite.

t is possible, in such things as connecting rods, that differences may be important. When they are, the de- er should consult the metallurgist and refer to the S- ves for the steels under consideration. When all mar- site is needed, there is no sense in kidding ourselves. actual full-martensitic depth hardening is sometimes a quarter of the depth we are ordinarily told a steel "harden" to.

Special Treatments: The designer may be intrigued apparent possibilities in certain deviations from the ventional quench-and-temper heat treatment and in cesses with fancy names. One of these is "austemper-" which is quenching into *and holding in* a molten-lead fused-salt bath held at a selected temperature. This ws the regulated production of bainite all through the tion if it is small enough. At, and only at, certain nar- ranges of hardness (varying with the steel) useful nbinations of hardness and toughness are obtained. joker is that even with high-carbon mildly-alloyed ls, the section must be under ¼-in. Even with high



. 9—Jominy band for different lots of NE 8744 all eting ordinary specifications. Dashed line shows average expectancy

y steels the usable sections are small. The process value but it has extreme limitations. Unless those lim- tions are observed, the result is worse than mediocre. Another process is "martempering" which involves enching in molten lead or fused salt held at the proper perature and giving the steel time for temperature lization but not enough time for production of bainite. tead of *holding* as in austempering, the piece is taken t at just the right moment, then cooled to produce the rtensite of the usual quench. This process has much ue in minimizing distortion and cracking but it too has joker. The hot-bath quench is so slow that a sluggish h-alloy steel is needed. Hence size limitations are ere though not so much so as in austempering.

Alloy Steel: This all sums up to the fact that heat- atable steels have properties dependent on carbon level d on structure, and not much else. Structure is a re- tant of response to cooling rate. To get the best structure, the proper response at the center of the piece must be obtained. In big pieces that response is attainable only by alloying the steel. "Alloy steel" then settles down to any combination of elements that will produce that response. This is a far cry from the old text book descriptions of alloy steels, and from the old claims of salesmen.

Fine-Grained Steels Are Tougher

Grain Size: Another factor, applicable to carbon and all alloy steels, irrespective of composition, is that of grain size. Fine-grained steels are tougher for a given strength than coarse grain. This used to be discussed under the term "body" of steel, and there was a lot of the occult tied up with it. That is all wiped away with the development of grain size standards, with methods for determining grain size and with the ability of steel mills to produce either coarse or fine grain in steel otherwise the same. One effect of grain size is indicated in *Fig.* 10.

It happens that, in the same steel, the fine-grained condition is less hardenable. But it is easy to produce a fine-grained steel of any desired hardenability by adjusting the alloy level. Thus, again, without any reference to composition aside from carbon level, a combination of grain size and hardenability requirements can be set up, and steels meeting them can be supplied for a specific use.

Weldability: Welding has assumed so much importance as an improved method of fabrication that the designer often would like to add weldability to other requirements. Broadly speaking, when weldability is required hardenability must be excluded. There are borderline cases, and important ones, where the high strength of quenched and tempered steels is used in welded structures but only with heat treatment after welding or with carefully controlled preheating and postheating in welding. In such cases metallurgical and welding experts must be consulted to see if the borderline case is practical. Sometimes a tiny heat-affected zone may not injure the structure. There are cases where strong heat-treated steels can be welded but these cases are exceptional and their design needs checking by a welding expert.

Mild Alloy Steels: The designer is not barred from the use of strong steels in welded construction. There are available a large number of mild alloy or "low alloy, high yield strength" steels that are satisfactorily weldable. They require no heat treatment to have about twice the yield strength of equally weldable plain carbon steels. Some are low-carbon sisters of the NE steel family, others differ in composition. In any case, the compositions are such that the steel is sluggish enough on air cooling, delaying the transformation sufficiently to produce a fine microstructure. Again, it is the structure rather than the composition that counts, so there is a multiplicity of equivalent steels. Most of them are a bit more resistant to atmospheric corrosion that carbon steel but they all rust quickly. For the uses of the machine designer, any of them must be painted, so for his purposes they are interchangeable. As a class they have better fatigue resistance than higher carbon grades of plain carbon steels.

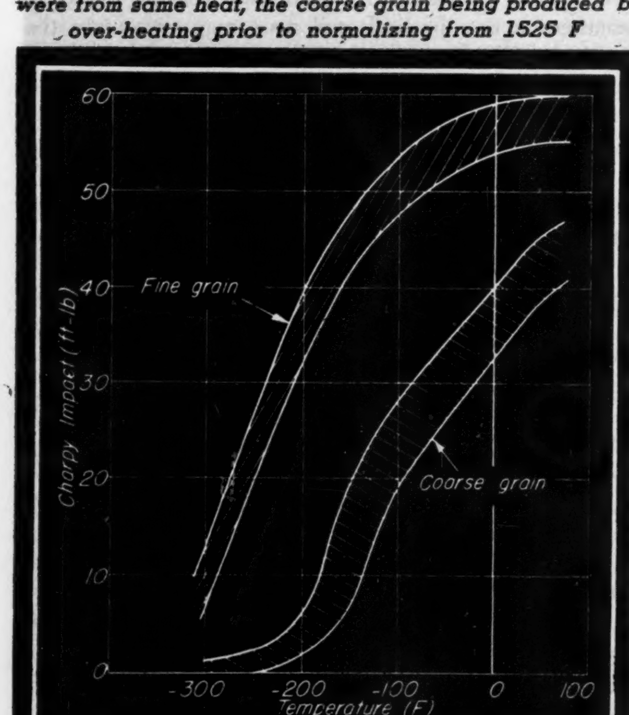
Machinability: Often the designer is charged with disregarding fabrication difficulties and specifying solely on the basis of final mechanical properties. If he omits

the matter of machinability, the production men will soon bring it to his attention. Here again, metallurgical and machine shop experts need to be consulted, because machinability may vary for different machine operations. Drilling and milling, for example, may rate two steels or the same steel with different structures, in reverse orders.

Without going into details, there are broadly two ways to improve machinability: (a) To alter the structure by cold work or by heat treatment, or (b) to add something to the steel. The machinability of cold-drawn stock is generally understood. The differences among heat-treated structures are not so clear. Suffice it to say that, when the structure finally wanted is not that which best lends itself to machining, a preliminary heat treatment can be applied to produce the easily-machined structure. After machining another treatment can confer the desired mechanical properties.

Method (b) adds some sort of "chip-breaker" to the steel, usually sulphur, which is decidedly effective but when carried too far is attended by severely decreased transverse toughness. This may or may not matter, depending on how the part is to be stressed. When it does matter, lead-bearing steel can be resorted to. A tenth of a per cent or so of lead vastly improves machinability, has almost no effect on strength or toughness and does not interfere with heat treatment. The lead addition can be made to carbon or alloy steels. Such steels are at the moment commercially available only in a few plain carbon grades and were held pretty much in abeyance in the U. S. during the war, although Britain made considerable and effective use of them for war purposes. The leaded alloy steels require special orders, but are worth remembering when high mechanical properties and a high order of machinability are both required.

Fig. 10—SAE 2315 normalized, 190 brinell. Specimens were from same heat, the coarse grain being produced by over-heating prior to normalizing from 1525 F



Conventional and Honest Criteria: In specify steel, the designer needs to do some real soul-search thinking about what properties the part he is design really needs. Granted he doesn't want a glass-brittle s but rather one with a trace of ability for plastic flow, should recognize that he can utilize only that small t in his finished design. (When dealing with fabricat processes involving cold-forming, one utilizes all the a ity for plastic deformation one can get, but that has n ing to do with ultimate service.) Far less ductility th normally associated with the necessary yield stre would be adequate.

Fatigue behavior limits the applicability of the v strong, nonductile steels, not because they lack ductil for fatigue failures are not conditioned by ductility, b because they are notch sensitive. If the designer c avoid notches or their equivalent in other stress rai and can be sure the user will not allow any notches to created in service, he can make use of stronger ste Watching out for decarburization is highly import where fatigue is concerned.

Impact notch toughness may or may not have any be ing on service. If it has, conventional tests are close valueless. The actual object needs to be tested. The is no assurance that two consecutive heats of the sa steel will act alike. So when this type of notch toughn counts, ordinary specifications do not specify.

Hardenability Should Be Specified

For parts to be quenched and tempered in large se tion, ordinary chemical specifications are inadequate; spe ification should be on hardenability. When interior pro erties are crucial, specification should be on 100% ma tensitic hardenability, but the service requirements for i terior properties must first be clearly understood.

Weldability and machinability requirements are spec matters with several ways of skinning the cat.

Mild alloy steels for non-heat-treated parts, and N steels for heat-treated ones greatly increase the ability the designer to choose a steel that will fit the job bett than when there was a choice only of carbon steel or so SAE steels. Today, the alloy contents are graded, rangin from mild alloy non-heat-treated steels with better pro erties than carbon steel to NE steels with properties equ to many of the SAE steels, at the cost of much less allo Present NE steel compositions are not sacred, vario other combinations will give gradations in hardenabili and will be utilized in the future. The way should b kept open to such use. There is obviously no sacredne about the mild alloy steel compositions, one of a dozen equivalent to any of the other eleven.

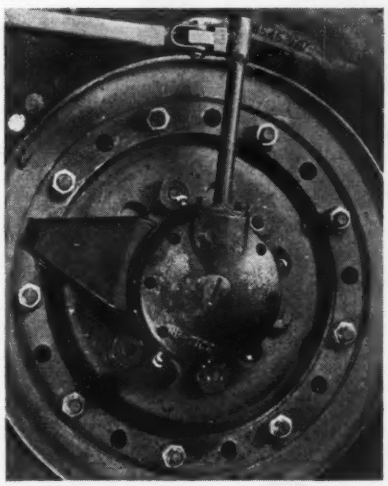
With these facts in view, the designer who specifi some expensive SAE steel—he used it in prewar times, worked well and he won't "take chances"—is cutti himself off from a cost saving. If he carefully examines j the properties the part really needs in service, that exam ination usually leads to a better product. If a part is fa ing, the trouble is cured more often by modifying the d sign a bit to meet the requirements of *any* reasonably a plicable steel than by groping for some super steel that o fondly hopes will stand up under impossible conditions.

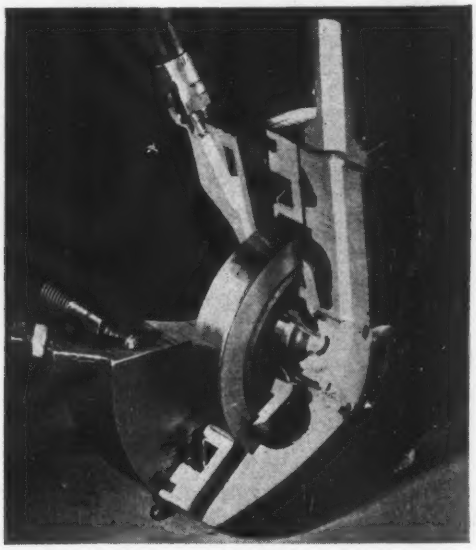
Scanning THE FIELD for Ideas

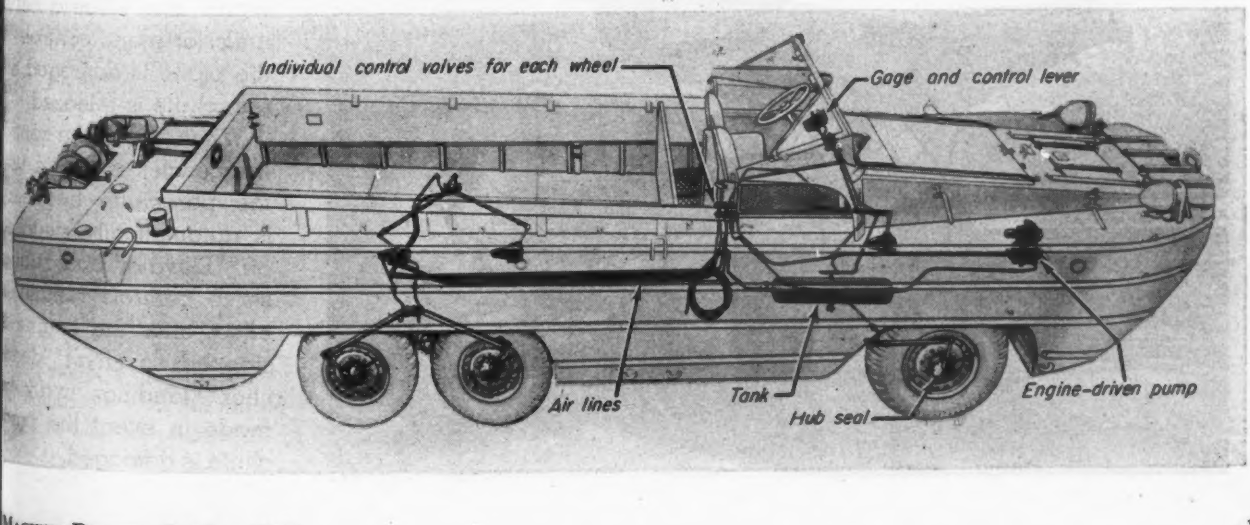
Central control of tire pressure, developed by General Motors Corp. for the Army's "Duck" enables the driver to inflate or deflate any or all tires whether the vehicle is stationary or moving. Thus the Duck could always have proper inflation whether operating on mud, sand or highway. When applied to peacetime vehicles, pressures for maximum traction and efficiency can be controlled easily by the driver without the necessity of any lost time.

In the phantom view below the system is shown applied to a Duck. Crux of the system is the rotating pressure seal attached to the wheel hub by special studs and screws. This seal is shown on a hub and in cutaway at right and is a refined design of several earlier units. The inner or rotating member turns with the wheel while the outer or stationary member is restrained by a flexible strut arm attached to the body of the vehicle. The air hose connecting the air line and the hub is carried within and protected by the strut.

To effect a rotating seal a hardened steel nosepiece of the rotating member is in contact with a plastic disk of the



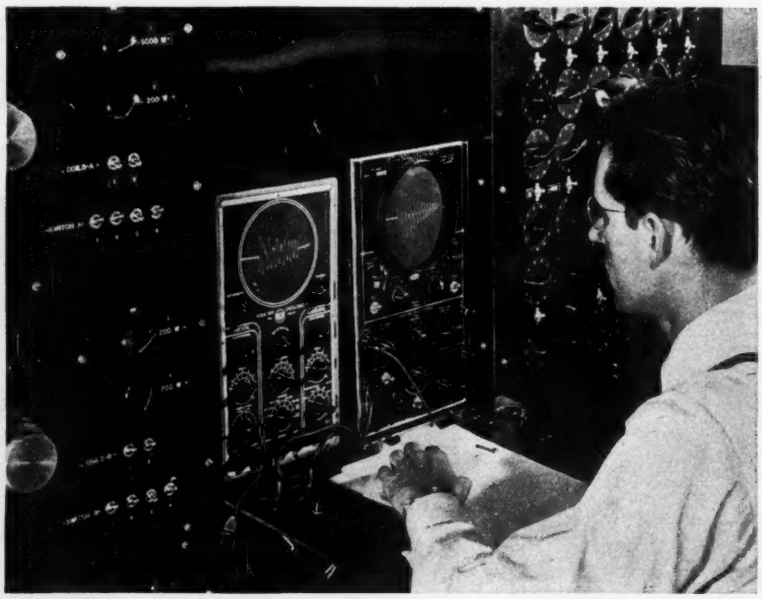




stationary member. By accurate grinding of the nosepiece and fine adjustment of the disk an air-tight seal is effected. A special, precision, heavy-duty ball bearing maintains close alignment between the two members and insures long life for both the joint and seal. Special precautions were taken to seal the unit against water by utilization of a large spring-loaded seal of synthetic rubber. Its design permits the release of pressure from within. An auxiliary outer seal prevents the entrance of dust or sand.

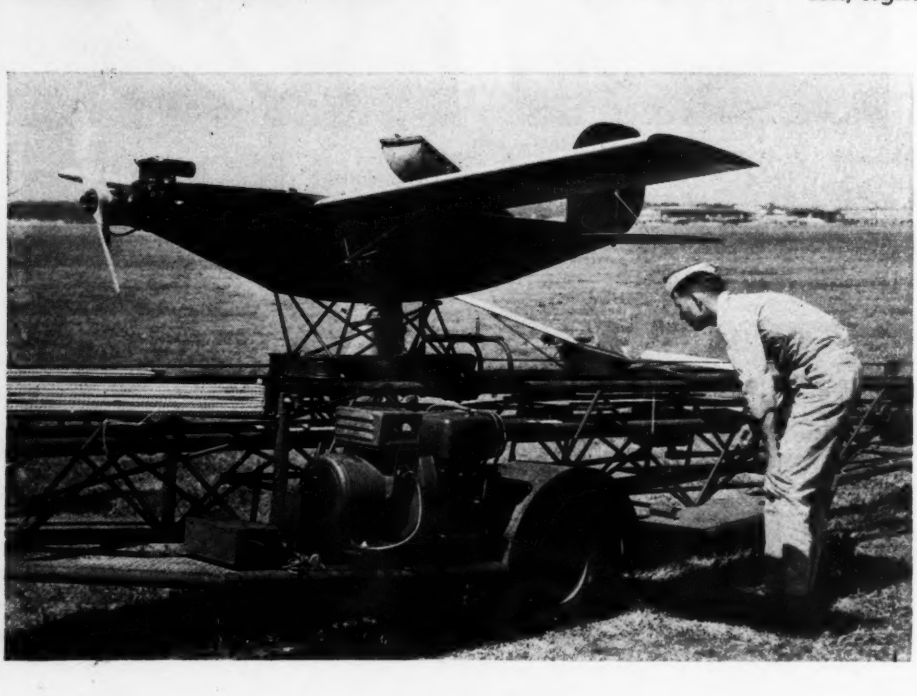
Intricate calculations may be performed readily on the me-chanical transient analyzer, shown below, developed by West-house Electric Corp. The apparatus does its speedy figuring electric circuits that duplicate everything in a mechanical probl and writes the answer with an electronic beam on the fluoresc screen of a cathode-ray oscilloscope. This electrical robot can made to work almost any mechanical motion problem that fa engineers today.

Radio-Controlled, pilotless airplane developed at the Technical Service Command has proved to be one of the U. S. Arm most ingenious training devices. Designed for use as a target pla in gunnery practice and later used to train students of radar, t development envisions practical power control by radio for pea time application.

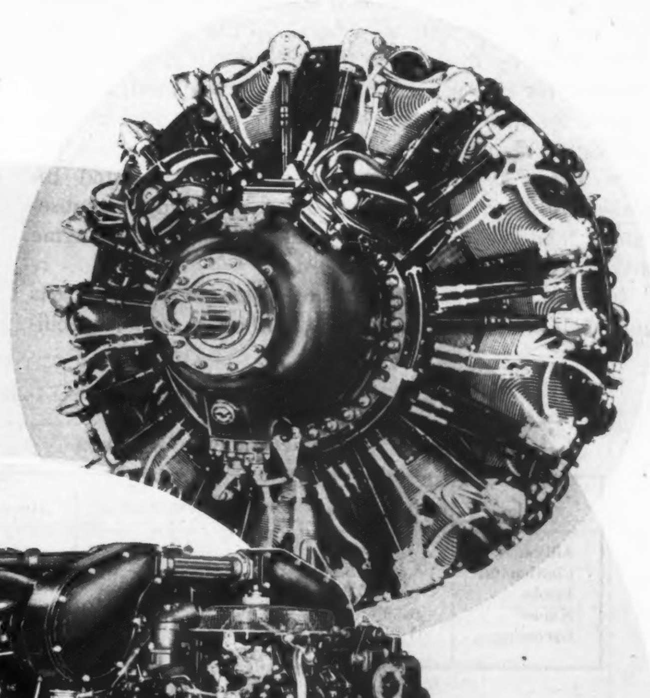


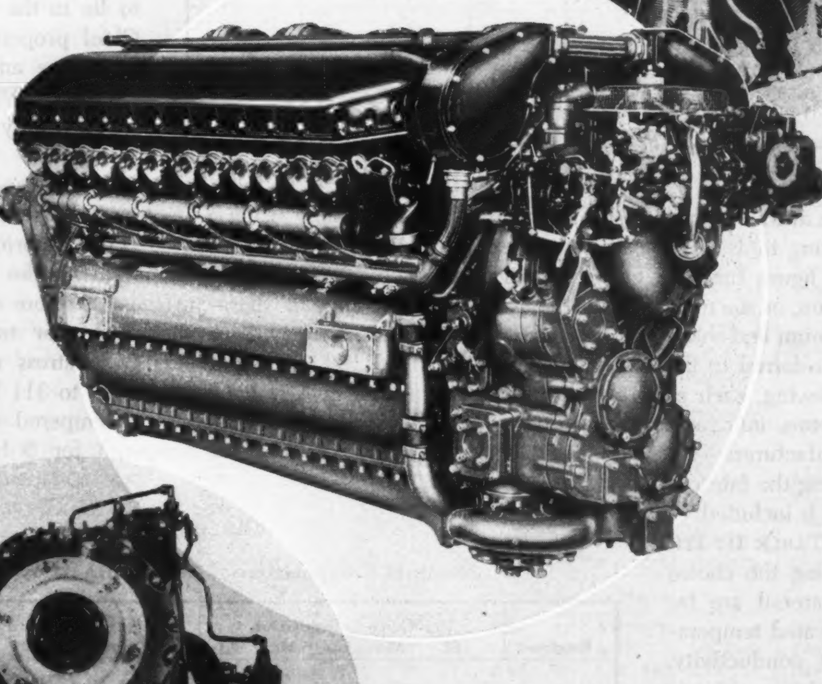
Illustrated below, the OQ-14 mod has a wing span of $11\frac{1}{2}$ feet, is pow-ered by a 22-horsepower engine a will fly 140 miles an hour at altitud up to 3000 feet. Takeoff is accom-plished by the use of a catapult, pow-ered by compressed spring coils or ru-ber shock cord. After launching, t plane is radio operated by elevator a rudder controls. The radio control i volves use of an ultrahigh-frequen carrier wave, modulated by five d ferent audio frequencies. A small co trol box attached to the transmitter b flexible cable, equipped with a sti to simulate airplane control, is em ployed to select the proper radio sig nals.

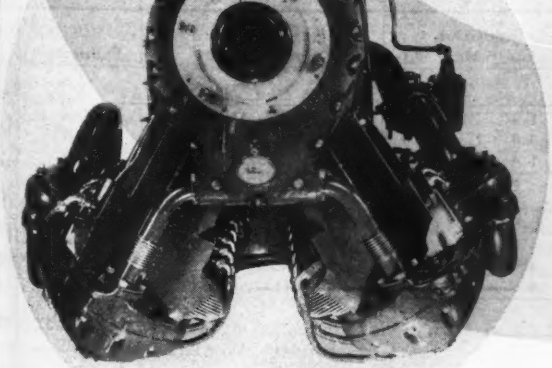
Four of the audio-frequency tone control the plane in flight, one each f left, right, up and down. The fifth fre quency centers the rudde and releases a parachut for landing. A radio re ceiver in the plane trans lates the signals and op erates the electric serv units for plane control. the plane is damaged th parachute is released.



When one of the contro frequencies is not in use the parachute frequenc is automatically switched on. Elevator and rudde servo controls remain i effect after the engine i stopped so that "dead stick" landings may b made in event the para chute is damaged.







Primary Factors in Choosing Aircraft Engine Materials

By Colin Carmichael
Associate Editor, Machine Design

VARIETY and severity of the service conditions to which aircraft engines are subjected compels the utmost care in selecting materials. Minimum weight must be combined with maximum reliability while due consideration must be given to ease of production in quantity. Because the problems of the aircraft designer are thus accentuated versions of those common to many other

fields of design, their solution should be of great interest and value to designers in general. In this article the materials used by five of the leading aircraft engine manufacturers for eighteen critical parts are compared, and the reasons for their selection and the processes used in their fabrication discussed.

In TABLE I the five engines discussed are listed, together with particulars of size and general type. In subsequent references only the initial letters of the engine makes will be used.

In TABLES II, III and IV are listed the various parts and their average compositions. Although actual specifications generally give maximum or minimum percentage or both, the accompanying tables have been simplified so as to include only one figure for each element, which may represent the maximum, or the minimum, or the average of the permissible minimum and maximum. For more specific details the reader is referred to the specifications listed in the table. In the following, each part is dealt with in turn and the primary factors influencing its selection—as reported by the manufacturers—discussed. Supplementary information concerning the fabrication of the parts also is included.

TABLE I

Particulars of Engines

Make	Designation	No. of Cylinders	Horsepower	Cooling
Allison	V-1710	12	1500	Liquid
Continental	A & C Series	4-6	50-150	Air
Jacobs	L-4 (R-755)	7	300	Air
Kinner	R-56	5	160	Air
Lycoming	O Series	4, 6 & 8	125-250	Air

CYLINDER HEAD, TABLE II: Primary factors governing the choice of cylinder head material are fatigue strength at elevated temperatures, and thermal conductivity. Low density, corrosion resistance and casting qualities also are taken into consideration. Solution heat treatment followed by precipitation (aging) is employed to improve the mechanical properties of these alloys. Typical specifications provide for a minimum brinell hardness number of 90 in Alcoa 142. In the case of AMS 4214 it has been found that high-temperature aging substantially reduces internal stress with only slight sacrifice in physical properties but greater endurance in the actual casting.

PISTON, TABLE II: In selecting piston materials, thermal conductivity appears to be the major consideration. Fatigue strength, wear restistance, low density, and corrosion resistance also enter into the picture in varying degree. It is of interest to note that both castings and forgings appear to be well suited to this application. In the experience of at least one company, a sound casting is every bit as good as a forging but the forging is preferred because of a lower rejection rate due to defects.

TABLE II

Nominal Composition of Aluminum Alloy Parts

Engine	Per Cent Composition Si	Mn	Cu	Mg	Ni	Specification	Fabrication
				Cylinder Head			
A	5.0	...	1.3	.5	...	AMS 4214, Alcoa 355	Cast
C,J,L	...	...	4.0	1.5	2.0	AMS 4220, Alcoa 142	Cast
K	5.0	.8	1.4	.5	.8	Alcoa A355-T5	Cast
				Piston			
A,J	12.5	...	.9	1.0	.9	AMS 4145, Alcoa 32S	Forged
C	12.0	...	.8	1.0	2.5	Alcoa 132A	Cast
K	...	...	4.0	1.5	2.0	Alcoa 142	Cast
L	...	...	4.0	.5	2.0	AMS 4140, Alcoa 18ST	Forged
				Crankcase			
A,C,J,L	5.0	...	1.3	.5	...	AMS 4214, Alcoa 355	Cast
K	1.2	...	4.5	...	...	Alcoa 195-T6	Cast

CRANKCASE, TABLE II: For crankcase materials, the desirability of light weight indicates the use of aluminum alloy. Provided the alloy has sufficient fatigue strength the next consideration is ease of production, primarily casting qualities and machinability. Tensile strength and corrosion resistance also merit due consideration. As indicated in TABLE II the AMS 4214 material is extremely popular for aircraft use. Its success is due to the satisfactory manner in which it meets the foregoing requirements, particularly that of freedom from foundry defects, a quality shared by Alcoa 195—one of the most widely used general-purpose aluminum casting alloys.

CRANKSHAFT: Reference to TABLE III indicates considerable agreement concerning crankshaft materials, the difference appearing to lie in the question of nitriding. Chief properties desired are wear resistance and tensile and fatigue strength. For this reason high hardenability is the basis for selection.

In the experience of at least one company using SAE 4340, this material in the quenched and tempered state (285 to 321 brinell hardness numbers) was not quite hard enough for the bearing surfaces. Nitriding of these surfaces therefore was adopted, in conjunction with a slightly higher tempering temperature (1150 F) which effectively stress relieves the part and still gives a hardness of 277 to 311 bhn. The unmachined forging is hardened and tempered (5 hours), semifinished machined, again tempered for 5 hours, bearings finished ground, and then nitrided all over. After nitriding the bearings are lapped and the shafts finish-machined.

CAMSHAFT: With wear resistance as the primary consideration, TABLE III indicates a three-way division of opinion—flame-hardened alloy cast iron, carburized low-alloy steel and carburized higher-alloy steel. The parts are relatively lightly loaded and in some designs were originally plain carbon carburizing steel (SAE 1020). However, such a material requires water quenching with consequent distortion, which becomes excessive in a long slender part.

t is interesting to note that as a result of flame hardening, he hardness of the alloy cast iron cam surfaces can be aised to more than 55 rockwell C.

Cylinder Barrel, Table III: With wear resistance gain the primary factor, choice of a material for the ylinder barrel is based on hardenability—provided the achinability is reasonably satisfactory, inasmuch as a irror-like surface is desired for the bore. Tensile strength, ndurance and shock resistance must, of course, be sufficiently high. Use of NE 8617 in one case is the result of a ubstitution for SAE 4615, a high nickel-alloy steel with olybdenum. The NE steel has roved to be just as satisfactory or this purpose. This particular ngine uses a seamless tube upset t the shoulder, carburized, ground nd honed. For noncarburized eat-treated parts the choice lies etween a plain carbon steel (SAE 050) hardened to 241-286 bhn, nd a low-alloy steel (NE 8740) ardened to 293-341 bhn.

Connecting Rod, Table III: nasmuch as tensile and fatigue trength are primary requirements f the connecting rod, hardenability s it effects the development of aximum strength throughout the ection is an important consideraion. Two engines use a high nickel teel (AMS 6415) which is harlened, tempered, and shot peened or increased fatigue resistance. Another engine uses plain carbon teel (SAE 1050) quenched and empered to a hardness 241 to 269 bhn. The NE 8740 steel in another ngine is heat treated to 277 to 311 bhn.

Reduction Gears, Table III: To develop the necessary fatigue trength and wear resistance in reduction gears several materials and processes are used. Simplest is the ow-alloy steel, NE 8640, oil quenched and tempered to 321-352 bhn. A similar steel, AMS 6322, is used in the heat-treated tate with the addition of shot peening to improve fatigue resistance, particularly at the roots of the teeth. Carburized gears of either high-alloy (SAE 3110) or low-alloy (NE 8620) nickel-chromium teel offer another solution. In general, only simple parts nd those with sections no greater than ½-in. thickness re made from NE 8620 because of the relatively unpredictable core hardness. Heavily loaded gears are made rom the higher-alloy steel.

Piston Pin, Table III: Wear resistance combined with esistance to repeated impact is the primary requirement f piston pin materials. Hardenability, for high core trength, therefore is an important factor in the choice f material. The necessary surface hardness for wear resisance (on the order of 60 rockwell C) is obtained by quenching, carburizing or nitriding. While rolled bar stock ordinarily appears to be satisfactory, the hammered bar offers the advantage of reducing hairline stringers.

Cylinder Studs, Table III: Tensile and fatigue strength are primary reqairements of cylinder studs, while due consideration must of course be given to machinability. Because of the need for maximum strength throughout the section, high hardenability is the principal criterion. The NE 8640 is tempered to 269 to 302 bhn while the NE 8740 is heat treated to 26 to 32 rockwell C, the threads being rolled to give added strength and accuracy.

TABLE III

Nominal Composition of Steel Structural Parts

Engine	Per Cent Composition C	Mn	Si	Ni	Cr	Mo	Specification	Treatment
Crankshaft (Forging)								
A,C,J,L	.40	.70	.27	1.82	.80	.25	AMS 6415, SAE 4340	Nitrided
K	.40	.80	.27	1.25	.65	...	SAE 3140	Tempered
Camshaft								
A	.17	.80	.27	.55	.50	.20	AMS 6272	Carburized
C	Alloy cast iron							Flame hardened
J	.14	.52	.27	1.82	...	.25	AMS 6290	Carburized
K	.20	.70	.27	1.25	.65	...	SAE 3120	Carburized
L	.14	.80	.27	.55	.50	.20	AMS 6270	Carburized
Cylinder Barrel								
A	.17	.80	.27	.55	.50	.20	AMS 6272, NE 8617	Carburized
C,K	.50	.75	...	...	...	...	SAE 1050	Tempered
J,L	.40	.87	.27	.55	.50	.25	AMS 6322, NE 8740	Tempered
Connecting Rod								
A,J	.40	.70	.27	1.82	.80	.25	AMS 6415	Shot peened
C	.50	.75	...	...	...	...	SAE 1050	
K	.40	.80	.27	1.30	.65	...	SAE 3140	
L	.40	.87	.27	.55	.50	.25	AMS 6322, NE 8740	
Reduction Gears								
A	.10	.55	.27	3.25	1.20	.11	AMS 6260	Carburized, shot peened
C	.40	.87	.27	.55	.50	.20	NE 8640	Tempered
J	.40	.87	.27	.55	.50	.25	AMS 6322	Tempered, shot peened
L	.10	.52	.27	3.50	1.57	...	AMS 6250, SAE 3110	Carburized
L	.20	.80	.27	.55	.50	.20	AMS 6274, NE 8620	Carburized
Piston Pin								
A	.10	.55	.27	3.25	1.20	.11	AMS 6260	Hammered bar
C,L	.20	.80	.27	.55	.50	.20	AMS 6274, NE 8620	Bar stock, carburized
J	.40	.60	.30	...	1.60	.75	AMS 6470 (1.12AL)	Bar stock, nitrided
K	.50	.87	.27	...	.95	.20	SAE 4150	Bar stock, hardened
Cylinder Studs								
A	.40	.70	.27	1.82	.80	.25	AMS 6415	Bar stock, tempered
C	.40	.87	.27	.55	.50	.20	NE 8640	Bar stock, tempered
J	.35	.70	.27	1.82	...	.25	AMS 6310	Bar stock, tempered
K	.30	.70	.27	3.50	...	...	SAE 2330	Bar stock
L	.40	.87	.27	.55	.50	.25	AMS 6322, NE 8740	Bar stock, tempered

Intake and Exhaust Valves, Table IV: Extreme severity of the service conditions for the valves, particularly the exhaust, are met in a variety of ways. Wear resistance, corrosion and strength, including shock reand corrosion resistance, and strength, including shock re-Medium or low-alloy steels appear to serve adequately for intake valves in certain engines, the SAE 3140 being heat treated to 60 rockwell C (minimum) and the NE 8740 hardened to 32 to 36 rockwell C except at the tip which is flame-hardened to 55 minimum for wear resistance. Use of the latter alloy is based on price but in larger engines it is found necessary to employ a stainless heat-resisting alloy. The Ferchrome D valves are Stellite tipped. The large valves used on the Allison engine are sodium-filled to aid

heat transfer, the stem being nitrided. A Stellite seat and a cobalt chromium alloy tip are welded on the valve stem. In another case where AMS 5700 is used the head has a nichrome coating, the seat is Stellite and the tip is flame-hardened SAE 1095. Incidentally, one user of this material is seeking an even better valve material to withstand corrosion brought about by highly leaded fuels.

VALVE SEAT INSERTS, TABLE IV: Wear resistance and corrosion resistance are major considerations in choosing valve insert material, while thermal conductivity also enters into the picture. Aluminum bronze and special alloy steels both are used. Of the bronzes, AMS 4632 is centrifugally cast and the Lumen 193 ATA is bar stock. In the experience of one manufacturer, aluminum bronze corroded badly when used on the exhaust side, necessitating a change to AMS 5700. Carpenter VSM when used on the exhaust side has a Stellite face welded on, the entire insert (except the Stellite face) being chromium plated for increased corrosion resistance.

TABLE IV

Nominal Composition of Valve Mechanism Parts

Engine	Per Cent Composition C	Mn	Si	Ni	Cr	Mo	Other	Specification
Intake Valve								
A	.45	.70	.55	14.00	14.00	.35	2.37W	AMS 5700
C	.40	.80	.27	1.25	.65	...	...	SAE 3140
J	.32	.65	2.50	8.00	12.75	...	...	AMS 5705
K								Ferchrome D
L	.40	.87	.27	.55	.50	.25	...	AMS 6322, NE 8740
Exhaust Valve								
A,J,L	.45	.70	.55	14.00	14.00	.35	2.37W	AMS 5700
C	Tungsten alloy steel							
J	.32	.65	2.50	8.00	12.75	...	...	AMS 5705
K								Ferchrome D
Valve Seat Inserts								
A	.70	.50	1.10	3.00	5.25			Carpenter VSM
C	Intake: Tungsten alloy steel. Exhaust: Aluminum Bronze							
J	89.5 Cu, 1.5Fe, 8.5Al							AMS 4632
K	78Cu, .2Sn, 5Ni, 3.5Fe, 11.2Al, 5Mn							Lumen 193 HTA
L	.45	.70	.55	14.00	14.00	.35	2.37W	AMS 5700
Valve Rocker Arm (Forging)								
A	.40	.70	.27	1.82	.80	.25	...	AMS 6415
C	.20	.80	.27	.55	.50	.20	...	NE 8620
J	.40	.70	.27	1.82	...	.25	...	AMS 6317
K	.40	.80	.27	1.25	.65	...	...	SAE 3140
L	.14	.80	.27	.55	.50	.20	...	AMS 6270, NE 8613
Valve Adjusting Screw (Bar Stock)								
A	.17	.80	.27	.55	.50	.20	...	AMS 6272
C	.20	.80	.27	.55	.50	.20	...	NE 8620
J,(L)	1.02	.35	.27	.35	1.45	.08	.25Cu	AMS 6440
K	.15	.50	.27	1.25	.65	...	...	SAE 3115
Push Rod (Tubing)								
C	.35	.75	...	...	...	...	...	SAE 1035
J	.30	.50	.27	...	.95	.20	...	AMS 6360
K								Shelby tubing
L	.30	.80	.27	.55	.50	.20	...	NE 8630
Cam Follower Roller (Bar Stock)								
A,J,(L)	1.02	.35	.27	.35	1.45	.08	.25Cu	AMS 6440
K	.15	.50	.27	1.25	.65	...	...	SAE 3115

VALVE ROCKER ARM, TABLE IV: Fatigue strength is the principal consideration in selecting material for this mechanical part. Low-carbon steels (NE 8620 and NE 8613) are carburized on the wearing surfaces (60 rockwell C) with core hardness on the order of 28 rockwell C. The medium-carbon steels are hardened and tempered, the AMS 6317 being shot-peened also.

VALVE ADJUSTING SCREW, TABLE IV: Wear resistance the criterion in choosing material for this part, is obtained either by carburizing a low-carbon steel or hardening and tempering a high-carbon steel (AMS 6440). Fatigue strength and shock resistance also are considered, with machinability an important factor.

PUSH ROD, TABLE IV: Tensile and fatigue strength govern the selection of push rod material, which usually is annealed or normalized seamless tubing. The NE 8630 tubing has a minimum strength of 95,000 psi while the SAE 1035 has 80 to 90 rockwell B hardness.

CAM FOLLOWER ROLLER, TABLE IV: Wear resistance and shock resistance, principal requirements of this part, are met by use of either a carburized low-carbon steel or a quenched and tempered high-carbon steel (AMS 6440). The latter material is preferred by some due to ease of manufacture over a carburized part.

LINK ROD: Only two of the engines discussed have an articulated mechanism requiring use of a link rod. Both designs are forgings to meet the necessary high strength requirements, one being SAE 3140 nickel chromium steel and the other AMS 4130 aluminum alloy (equivalent to Alcoa 25S which contains nominally .8 per cent Si .8 per cent Mn and 4.5 Cu.)

CONCLUSION: The foregoing survey brings out two important points. First, in many cases the differences in composition used by various manufacturers are relatively insignificant, indicating that service and manufacturing requirements point inevitably to a definite type of alloy for a particular part. Possibly the number of different specifications could in these instances be reduced to a single composition which would satisfactorily serve for each design.

For certain other parts various designers have approached the selection problem from different angles. For example, hard surface is obtained by quenching, by carburizing, or by nitriding, the materials in each case being radically different. The variety of ways in which problems such as this can be met gives the designer considerable freedom, but places on him a responsibility to investigate the relative merits of each for his particular design.

MACHINE DESIGN acknowledges with appreciation the cooperation of the following in supplying information for this article: Allison Division of General Motors Corp.; Continental Motors Corp.; Jacobs Aircraft Engine Co. Division of Republic Industries Inc.; Kinner Motors Inc.; Lycoming Division of the Aviation Corp.

Fig. 1—Special grade of phenolic molding compound for housing of blow gun compensates for expansion difference between housing and the metal insert (photo courtesy Durez Plastics & Chemicals Co.)

Utilizing Plastics at Temperature Extremes

By John Delmonte

Technical Director
Plastics Industries Technical Institute

BEHAVIOR of plastics at extremes of cold and heat often has a decided bearing upon their successful application as parts of machines. This is particularly true where plastics and metals must complement one another in a given design. In such cases, it is necessary to examine the specific thermal properties of metals and plastics which are at variance, and inject compensating features which will make the designs possible and practical.

Properties of plastics will vary considerably with changes in temperature, and their correct use must anticipate extremes of service conditions. In a previous article* the writer has given some data on the ultimate strength of various plastics at short-time exposures to temperature extremes, from which the following observation may be drawn:

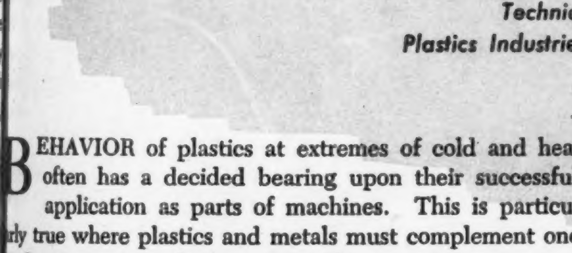
1. Ultimate compressive strength, tensile strength, and shear strength of most plastics will decrease as temperature increases, most thermoplastics changing more rapidly than thermosetting compounds, particularly among highly plasticized compounds
2. Impact strength and creep rate will increase as temperature is raised, and plastics generally are observed to be "tougher" at higher temperatures
3. Electrical properties such as resistivity fall off noticeably after certain temperature limits are passed
4. General resistance to chemicals decreases appreciably as temperature is raised.

Permanent changes in properties are observed at room temperatures after long-time exposure of plastics to high temperatures. These changes are dependent upon the chemical identity of the plastic and its formulation. In general, the properties of most thermosetting phenolics are substantially unaltered by continuous exposure to temperatures not exceeding 250 F., though some evidence of continued polymerization is manifested by "after-shrinkage". On the other hand, thermoplastics also may suffer some "after-shrinkage", occasioned by evaporation of volatiles, notably plasticizers, at higher temperatures.

Thermal properties of greatest interest to machine designers are thermal expansion and contraction, and heat

*"How Much 'Real Muscle' Do Plastics Offer the Designer?", MACHINE DESIGN, Page 99, Dec., 1944.

Fig. 2—Radiating fins of stud serve to dissipate heat and thus prevent knob from getting too hot to handle



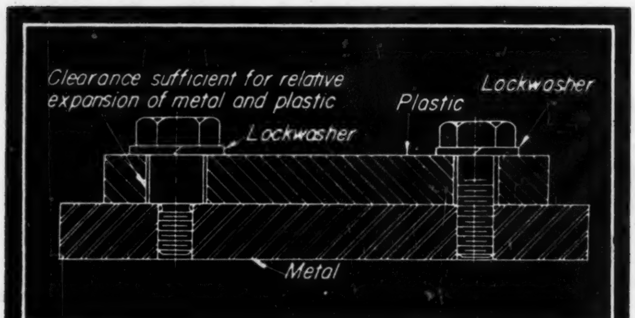


Fig. 3—In bolted plastic-to-metal assemblies, clearance holes should be sufficiently large to permit relative expansion of the plastic and metal members

conductivity. On the average, plastics expand two to ten times as much as metal, and when large metal inserts are to be included in molded plastics, the consequences of unequal expansion coefficients should be studied. In TABLE I the coefficients of expansion of various materials are tabu-

TABLE I

Thermal Properties of Representative Plastics

Type of Material	Coef. of Thermal Expansion	Thermal Conductivity (10^{-4} cal/sec/ sq cm/deg C)	ASTM Heat Distortion Temperature
Phenol-formaldehyde, mineral filled	.00002–.00004	10–20	310 F
Phenol-formaldehyde, cellulosic filled	.00003–.00004	4–7	260–300 F
Phenol-formaldehyde, laminate (Grade C)	.000017–.000025	5–8	>320 F
Urea-formaldehyde (alpha cellulose)	.000025–.00003	7	....
Melamine-formaldehyde, mineral filled	.00002–.000045	...	266 F
Polyamide	.00010	6	152 F
Polymethyl methacrylate (molded)	.00007–.00009	4–7	125–190 F
Polystyrene (molded)	.00006–.00008	1.8–2.0	178 F
Cellulose acetate (molded) flow temp., 288-306 F	.00011–.00016	4–8	140–175 F
Ethyl cellulose (molded)	.00010–.00014	4–6	120–200 F
Polyvinylidene chloride	.000158	2.2	150–180 F
Polyvinyl chloride, acetate (rigid)	.00007	4.0	140–150 F
Steel	.000011	1150	....
Brass	.000018	2600	....

lated. It will be noted that most plastics have a higher thermal expansion coefficient than representative steel and brass, a condition which may result in excessive stress concentrations. The stresses arising may not be due to thermal expansion or contraction alone, but may be due to the much greater differences of heat conductivity. In fact, one method of avoiding excessive stress concentrations is to attempt to minimize the differences in heat conductivity between plastics and metals.

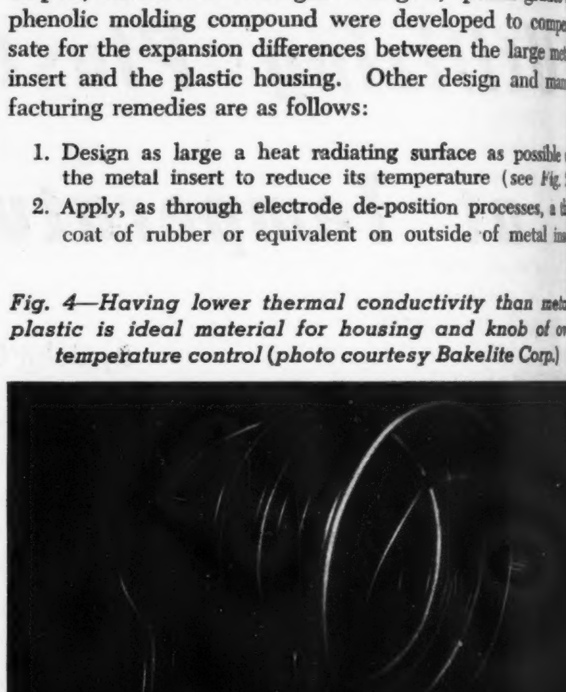
Relationship of Conductivity and Expansion

If the metal conducts heat much more rapidly than the plastic, it may expand initially more than the plastic due to its faster temperature rise. Thus, in spite of the higher coefficient of expansion of the plastic, it has been the writer's experience that mechanical failure in the plastic due to development of excessive stresses may in fact be due primarily to the early rapid temperature rise of the metal. Such phenomena are apparent particularly when molded plastic parts employ metal inserts which are attached to metal castings subject to considerable heat.

While the development of metal inserts with the same coefficient of expansion as the thermosetting plastics has been achieved in certain aluminum alloys, the effects of sudden temperature gradients are still acute. Where temperature changes are relatively slow, articles such as special binoculars developed for the Navy have attained a high degree of precision in combinations of molded phenolic plastics and special aluminum alloy inserts. In other examples, such as the blow gun in *Fig.* 1, special grades of phenolic molding compound were developed to compensate for the expansion differences between the large metal insert and the plastic housing. Other design and manufacturing remedies are as follows:

1. Design as large a heat radiating surface as possible on the metal insert to reduce its temperature (see Fig. 5)
2. Apply, as through electrode de-position processes, a thin coat of rubber or equivalent on outside of metal insert

Fig. 4—Having lower thermal conductivity than metal, plastic is ideal material for housing and knob of oven temperature control (photo courtesy Bakelite Corp.)



If the metal insert is a long, continuous strip and is to be bonded to plastic along the entire length, divide at frequent intervals, say every inch, or introduce expansion joints at frequent intervals

Introduce about the insert at the time of molding, a preform of asbestos-filled phenolic which not only will take higher temperatures, but which will conduct heat more readily and hence reduce the temperature gradient in the plastic at the edge of the metal insert

If the metal component is a long, continuous strip not bonded continuously to the plastic, employ oversize attachment holes, *Fig.* 3, calculated on the basis of relative expansion ($L_t = L_o[1+KT]$), where L_t is final length, L_o is original length, T is temperature difference in degrees Cent. and K is coefficient of expansion

Allow ample wall thickness about metal inserts, at least 0.093-inch. Design adequate reinforcing ribs to the plastic surrounding the insert. The ribs not only stiffen the part, but insure absence of flow or weld marks about the insert, which would weaken the plastic considerably.

ADVANTAGES OF LOW THERMAL CONDUCTIVITY: Whether the part is to operate at high or at low temperatures, the advantages of plastics are readily apparent if the part is going to make contact with the hand or some

Fig. 5—Because plastic housing of this hand grinder has low thermal conductivity, it does not overheat as would metal housing and is comfortable to the hand (photo courtesy Durez Plastics & Chemicals Co.)

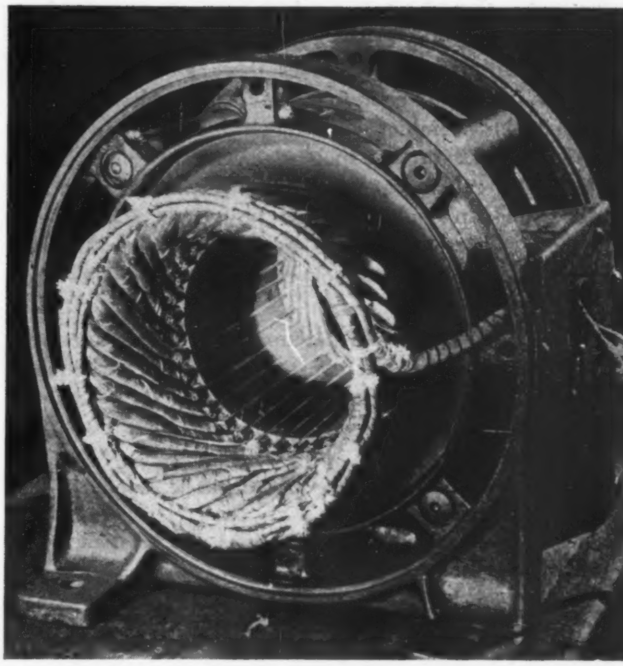
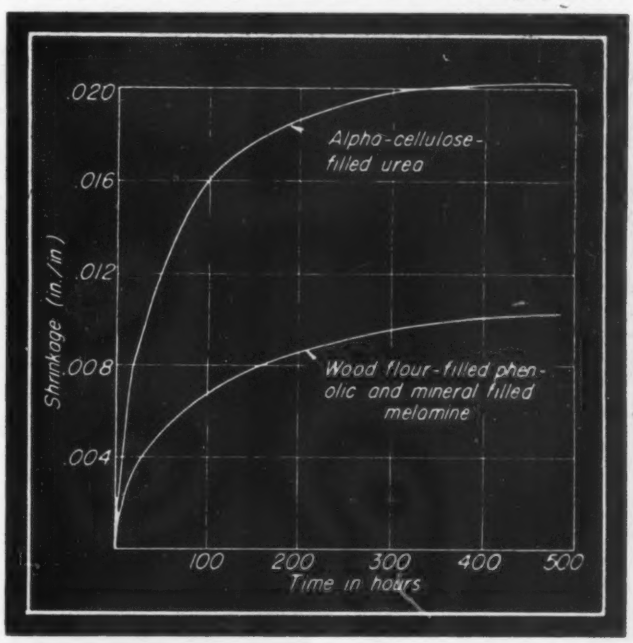


Fig. 6—Above—Silicone insulation on stator windings of motor permits higher operating temperatures, thus more power per unit weight (photo courtesy Dow-Corning Corp.)

Fig. 7—Below—Curves show "after-shrinkage" at 190 to 200 F for some representative thermosetting plastics



other part of the body. Of much lower thermal conductivity than metals, plastics are more comfortable to the touch and for this fundamentally important reason we find parts such as oven temperature controls, *Fig.* 4, molded in an integral unit. Another representative application is the molded plastic housing for a small hand grinder, *Fig.* 5. In a metal housing the part would be so uncomfortable to the touch in a few minutes due to the heat losses

of the motor that the unit would in very short order become unpopular.

Among the plastics themselves there are considerable differences in thermal conductivity. For example, asbestos-filled phenolics conduct heat much more rapidly than other types, and in articles such as electric flatiron handles, or handles for cooking utensils, the lower heat conductive woodflour-filled phenolics may be preferred. The latter, of course, would be acceptable only if the temperature attained by the plastic did not exceed its safe allowable limit.

Maximum Operating Temperatures: The question often is raised as to what constitutes the safe maximum operating temperature for a plastic material. It is obvious that the answer to this depends upon:

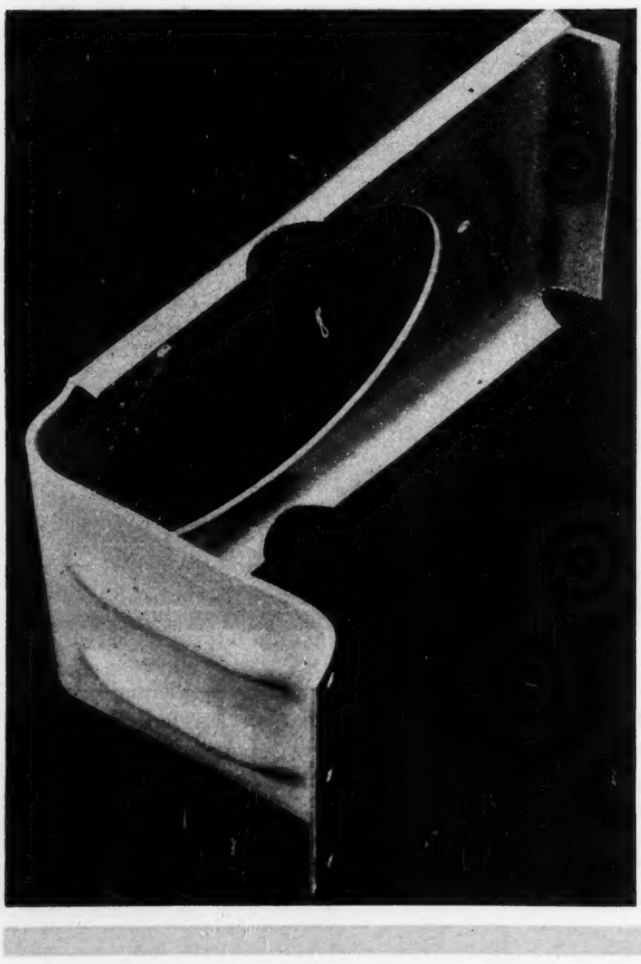
1. For what period of time the plastic will be exposed to the high temperature
2. What the prevailing physical stresses will be at the time the plastic is exposed.

The ASTM heat-distortion temperature represents a practical measurement based on temperature as well as stress, and safe working limits are suggested by the values which are tabulated in Table I. However, there are a few newer thermoplastics not included in this table which have ASTM heat-distortion temperatures considerably higher. These are "Cerex" and "Styramic HT" which are the first injection molding materials capable of withstanding boiling water. This important advance will influence numerous machine designs which contend with hot fluids.

The silicone resins are the most outstanding in their high-temperature stability. They have already exerted a decided influence on the design of electric motors and, in the unit illustrated in *Fig.* 6, permit much higher operating temperatures and a big jump in horsepower per unit weight.

†*Modern Plastics*, Vol. 20, Page 88, Feb., 1943.

Fig. 8—Thermosetting plastics develop thermoelasticity at very high temperatures, permitting them to be formed into shapes such as this aircraft dome-light mounting bracket (photo courtesy North American Aviation, Inc.)



Glass Cloth Laminates Have High Flame Resistance

With few exceptions, it will be found that most plastics have well defined ignition points in exposures to hot flame. A number of these ignition points have been determined by the writer†. In particular, melamine plaster laminates with a glass cloth base showed no tendency to burst into flame when held at temperatures of 1500 F. This means that flame or fireproof walls between aircraft engines and fuselages are quite practical in certain of the laminated plastics.

When plastics are operated continuously at high temperatures it is always imperative that the designer ascertain the extent of "after-shrinkage". Some representative values are shown for various thermosetting plastics in Fig. 7. These values are fairly large and if the development of appreciable "after-shrinkage" would interfere with the proper functioning of the plastic, an "after-bake" period following the conventional molding operation is suggested. In this manner a more dimensionally stable plastic part is assured in service.

Post Forming of Laminates: Thermosetting phenolic laminates exhibit some thermoelasticity at very high temperatures. Because of this unusual property, it has been found possible to form flat sheet stock into curved shapes fulfilling numerous industrial uses. A typical aircraft part formed in this manner is shown in *Fig.* 8. This technique, developed at North American Aviation Corp., greatly extends the usefulness of laminated canvas in machine design. Simple and compound curvatures may be drawn with relatively inexpensive jigs and dies. Finished parts demonstrate a decided weight saving and fabrication cost advantage over metal equivalents. It is quite probable that formed laminates will find their way into the design of housings for large machines, guards for rotating parts, chutes and channels where the sound absorption and wear resistance of phenolic laminates are desirable, and many other applications.

By these and other fabricating techniques, the susceptibility of plastics to temperature changes often has been capitalized upon to advantage. When temperature influences are understood, the designer can confidently dispel hesitation about adapting plastics to his machine.

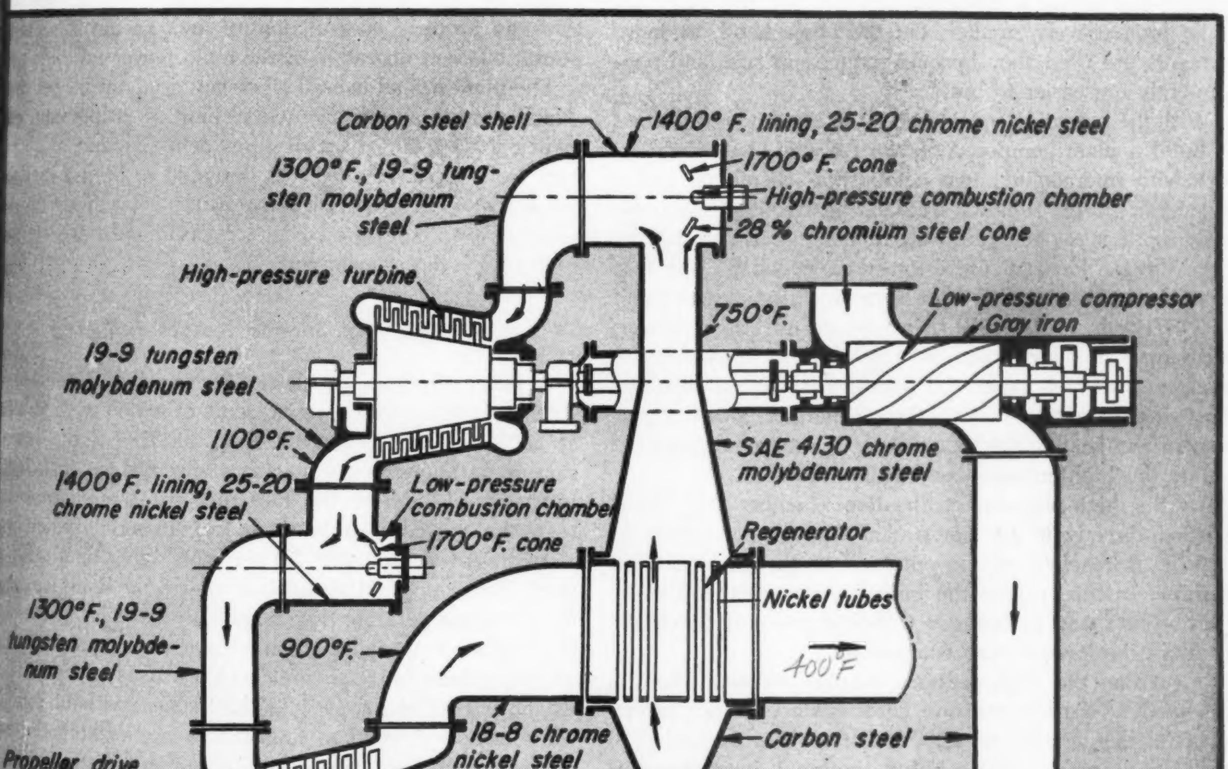
Materials Problems in Gas Turbine Design

By J. F. Cunningham and R. A. Riester

Elliott Co., Jeannette, Pa.

ONE OF the major problems in designing a successful gas turbine plant is that of finding suitable materials for operation at the high temperatures required for a thermal efficiency comparable to that of a steam turbine or diesel engine. How the materials problems were solved in the case of the 2500-hp gas turbine power-

. 1—Diagram of Elliott-Lysholm gas bine cycle, showing temperatures at each ge and materials used for critical parts



plant recently built by Elliott Co. for the U. S. Navy will be discussed in the present article. In addition the design measures which had to be taken to minimize the effects of distortion due to temperature differences, as well as to protect certain parts from excessive heat, will be explained.

Before considering these problems, however, the leading characteristics of the design and the factors affecting the choice of cycle will be discussed. It should be pointed out that there are many combinations of turbines, compressors, combustion chambers, intercoolers, and regenerators which can be used to produce a good, workable gas turbine plant. These range from the simplest group consisting of one turbine, one compressor and one combustion chamber —as employed for aircraft jet propulsion—to the more complex schemes combining several of each of these units with supplementary intercoolers and a regenerator.

How High Efficiency Is Obtained

A regenerator has a great effect in raising the efficiency of the machine. Addition of an intercooler and a second combustion chamber and turbine also increase the expected economy. The use of still another stage of intercooling and reheat is advantageous too, but the gains become progressively smaller. On the other hand, as more elements are used they become reduced in size, and consequently are easier to build.

With the foregoing considerations in mind it was decided to build a plant composed of two turbines, two compressors with intercooling, two combustion chambers, and a regenerator. *Fig.* 1 shows a schematic layout of the cycle and *Fig.* 2 is a photograph of the completed plant. Flow begins at the low-pressure compressor, which takes in free air and compresses it to a pressure of 43 psi absolute and 300 F. The temperature is then lowered in the intercooler, whereupon the air passes directly into the high-pressure compressor which raises the pressure to 96 psi absolute. The air then passes through the regenerator, where a portion of the heat in the exhaust gas is recovered before it enters the high-pressure combustion chamber.

In the high-pressure combustion chamber fuel oil is burned directly in the air stream and a temperature of 1230 F is reached at the entrance to the high-pressure turbine. In this turbine the heated air is expanded to 53 psi absolute, and in doing so sufficient power is developed to drive the low-pressure compressor.

Air from the high-pressure turbine exhaust then is reheated in the low-pressure combustion chamber to elevate its temperature to 1207 F before it is expanded in the low-pressure turbine. Five thousand horsepower is realized from the low-pressure turbine, 2500 of which is expended in driving the high-pressure compressor. The remainder is excess power which, in a marine gas turbine, drives the propeller.

After the air leaves the low-pressure turbine at slightly above atmospheric pressure, it passes to the regenerator where it preheats the fresh compressed air from the high-pressure compressor. The exhaust gas passes up the stack at a temperature of 400 F and is discharged to atmosphere.

General arrangement as shown in the sketch, *Fig.* 1, indicates that the two compressors are driven by separate turbines. This is not an essential feature of a plant containing two turbines and two compressors, but it is a desirable one which in this case was selected for a particular reason. Naval power plants operate more than 90 per cent of the time at other than full load and it is therefore important to have highly efficient part-load performance. The arrangement of machines in a gas turbine cycle, with individual turbine drives for the compressors, makes it possible to achieve this result.

To explain briefly why this is true, it should be pointed out that to reduce the power output it is necessary either to decrease the amount of hot air passing through the turbines or to reduce the temperature of the air. It may be necessary to do both. Inasmuch as the best efficiencies are realized when the temperature of the compressed air is as high as possible before being put to work in the turbine, it is desirable to operate at reduced power by decreasing the supply of air rather than by reducing the gas temperature. The best approach to high-temperature, reduced-flow operation is realized in this plant because the components are so arranged that the main power turbine can be operated always at full temperature.

Complete control is obtained by regulating the fuel flow to the turbine driving the low-pressure compressor. Since the amount of air which enters the system is controlled by this compressor, it is apparent that this one feature can produce ease of control and, at the same time, permit efficient operation of the main power turbine.

The plant has an overall efficiency of about 29 per cent which compares with a practical limit of 26 per cent efficiency for a steam plant of equivalent size and of 33 per cent for a diesel engine. It is designed to burn a medium grade fuel oil but the possibility of using lower grades and perhaps even powdered coal, or gas or oil derived from coal, also is being explored.

Thermal Expansion a Serious Problem

A major problem of elastic design must be solved in setting up any group of units, some of which are operating at 1200 F and others at 100 F to 300 F. Thermal expansion is particularly acute with a gas turbine installation since, in addition to the fact that the temperatures are high, the turbines must be made from materials which have a coefficient of expansion 50 per cent higher than ordinary steel. For example, the turbines are nearly ½-in. longer at operating temperature than when they are cold. This makes it necessary to design these machines, their mountings, and all parts connected to them in such a way as to permit these expansions to take place in a short space, without pushing the machines from their foundations or breaking the connecting pipes. It is also essential that thermal strains not be imposed on the various machines, since the lightweight structures which are subjected to high temperatures may be seriously distorted.

Both the high and low-pressure turbines are solidly mounted at their exhaust ends, with all expansions taking place toward the inlet of the machines. In order to permit this expansion it was necessary to secure these floating ends by means of freely moving links. Relative movement between the turbines and the compressors they drive is absorbed by double flexible couplings and long torque tube jackshafts.

A major problem of temperature control was posed by the fact that the high-pressure turbine inlet temperature

aches 1230 F whereas the main shaft bearings—approximately ten inches away—must operate at temperatures below 200 F. In order to make this possible, special methods had to be employed to prevent the free conduction of heat to undesired locations, which resulted in the use of systems of heat dams and special oil cooling at the bearings, and air cooling at the pin rings. The pin rings at each end, which support the full weight of the turbine, are so constructed that a 600 F temperature drop takes place in the connections between them and the inlet casing. This is accomplished by using small areas of contact, reduced metal sections to cut down heat conduction, and some well-placed air cooling on the inside of the pin rings.

A further temperature drop takes place in the bearing casing, and here again a problem exists. The inside flange of the bearing casing reaches 550 to 600 F, but five inches away the temperature can be only about 200 F. This makes it necessary to have symmetrical and uniform sections for the walls of the casing, to prevent excessive and uneven temperature strains.

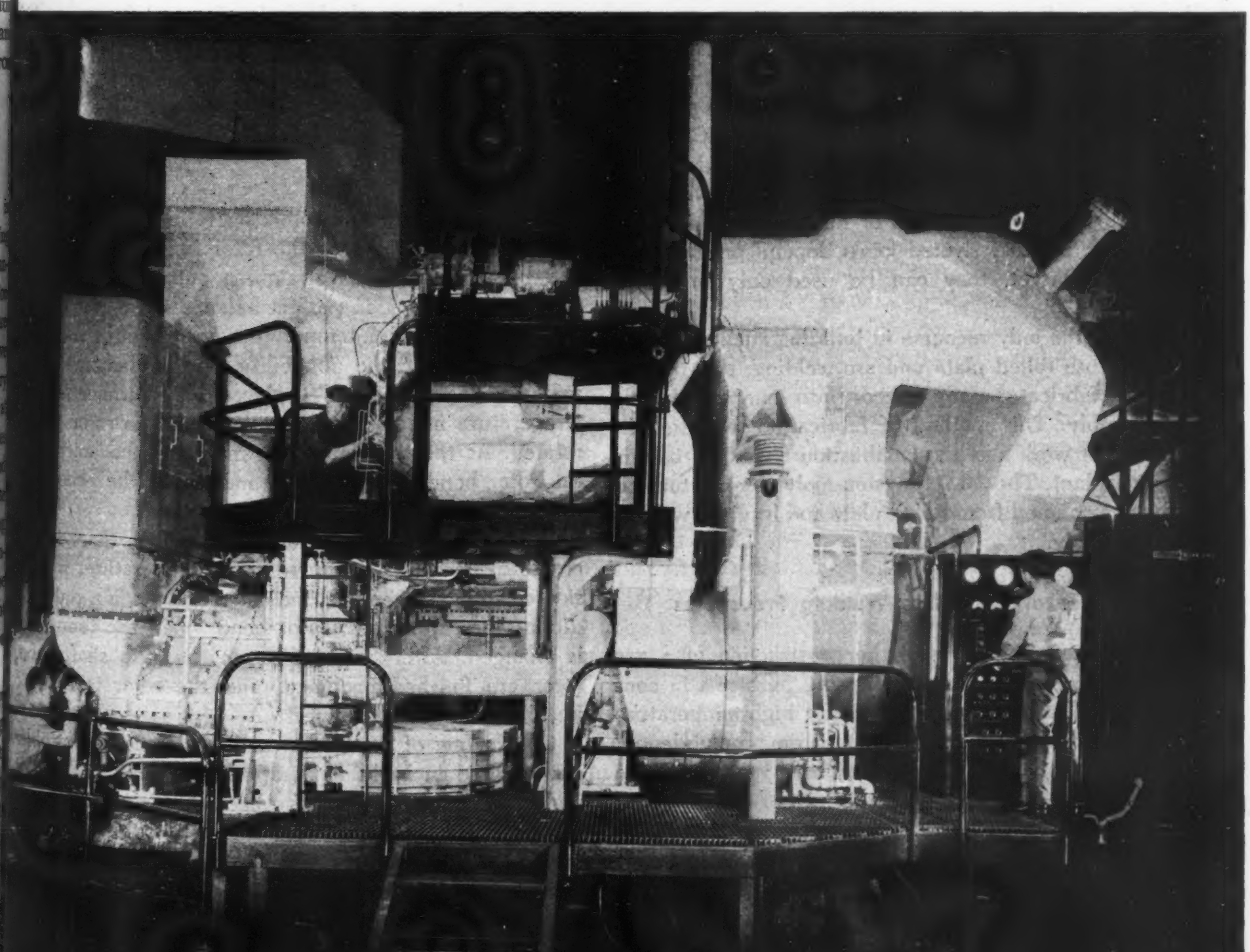
The shaft must be designed in a similar manner. Here again it was necessary to design the stub shaft ends with reasonably light walls so that the heat conduction is kept to a minimum. A radiation shield is installed inside the shaft to prevent exposure of the cool end of the shaft to the red hot inner regions. In addition to this, oil cooling is provided under the bearing journal sleeves.

One other outstanding feature is that all main members are tied together by means of radial pins which permit a free movement between adjacent parts that experience temperature differences. In other words the pin rings, diaphragms, and gland assemblies are all free to expand unrestrainedly with respect to their adjoining members. This is a heat-elastic design and construction which has eliminated many of the problems that brought disaster to others who have previously attempted to build gas turbines.

It was even imperative to devise a method for getting the machines unbolted after they had been operated at temperature. The stainless steel alloy which must be used in these turbines has the undesirable characteristic of galling when two parts are assembled together. This makes it impossible to take the nuts and bolts apart unless a suitable compound is previously used on the threads. A great many such compounds are sold but none was satisfactory for the temperatures at which our plant operates. It was therefore necessary to devise a special colloidal silver compound to do this job.

In *Fig.* 1 are indicated the maximum temperatures at each major stage and the materials used for critical parts. It will be noted that two machines—the high-pressure and the low-pressure turbines—and a considerable part of the duct work operate at a temperature high enough to make the steel visible in the dark, that is, at a red heat. The

Fig. 2—Side view of 2500-hp gas turbine marine powerplant, which is operated from control panel at lower right



physical characteristics of metals at these high temperatures is a problem in itself.

Because of creep it is certain that, after some period of operation, the turbine rotors will grow, the flat-sided ducts will bulge, and the round ducts will grow too large and too thin. It is the designer's problem to choose materials and loadings of such character that these changes will not be obnoxious before a certain definite time in terms of hours of operation. The present plant is designed for 10 years of continuous high-temperature service.

Heat-Resistant Materials Extensively Used

As will be seen from *Fig.* 1, a fair gamut of materials has been run on this job. The nickel torroidal joints in the high-pressure combustion chamber inlet were an interesting problem. This duct is made of chrome-molybdenum steel to operate at temperatures up to 1000 F. The torroidal joints are spinnings, 0.025-in. thick. If made of chrome-molybdenum steel they would be subject to scaling, which would be dangerous in that the material already is of minimum thickness. Austenitic stainless steels have a higher coefficient of expansion than chrome-molybdenum steel, which would cause intolerable differential stresses; and ferritic stainless steel cannot be spun successfully. Copper alloys have high coefficients of expansion and poor high-temperature properties. Nickel is usually a work-hardening material which cannot be spun, but at our request a special grade of cold-rolled "A" nickel which could be spun was produced in small quantities.

Use of high-temperature materials creates so many manufacturing problems that the only possibility of successful construction comes through extremely close cooperation of the manufacturing and design departments. Castings, though simple and convenient to design, are hard to produce in high-temperature alloys and do not have high-temperature properties of rolled or forged material of the same analysis. Because riveted joints depend primarily on tension in the rivet, they can be used only in minor attachments.

In general, the only recourse in building such machines as this is to use rolled plate and arc welding, and by this method to fabricate many pieces into one permanent single assembly. This method of fabrication was used in all of the duct work and the combustion chambers in this gas turbine plant. The 19-9 tungsten-molybdenum turbine rotors were machined from rolled plate and forgings welded into an assembly.

Importance of Controlled Welding Procedures

Extended use of welding in the construction of a gas turbine plant brings up some interesting problems in connection with welding on materials fit for high-temperature service. As an instance, SAE 4130 chrome-molybdenum steel is of an air-hardening variety. There is considerable danger that when a weld is made the heat of the weld will cause an extremely hard, brittle zone directly adjacent to the weld. This characteristic is more pronounced in heavy material than in light, due to the quicker cooling of the welds. As a result, it is necessary to check each weld prior to its being made, to set up procedures and to determine whether or not preheating is required.

The welding of 19-9 tungsten-molybdenum material was a completely new problem. No welding had been done on this alloy prior to the design of this gas turbine plant. In order to weld this material, it was necessary to develop a welding electrode, all existing electrodes having been tested and found to be short of the necessary high-temperature strength.

Not only did the new electrode have to possess strength but tests were necessary to ascertain the operating characteristics of the electrode, as there were some unusually difficult welds on the job. When the best operating characteristics had been obtained, extended tests were made as to the best procedures to use in laying weld metal. During these tests trouble was encountered in connection with cracks in the welds. This trouble was run down and found to be a matter of analysis of the core wire used in producing the electrode. Without going through all of these stages, there would have been little chance of building the high and low-pressure rotors for the turbines in this plant.

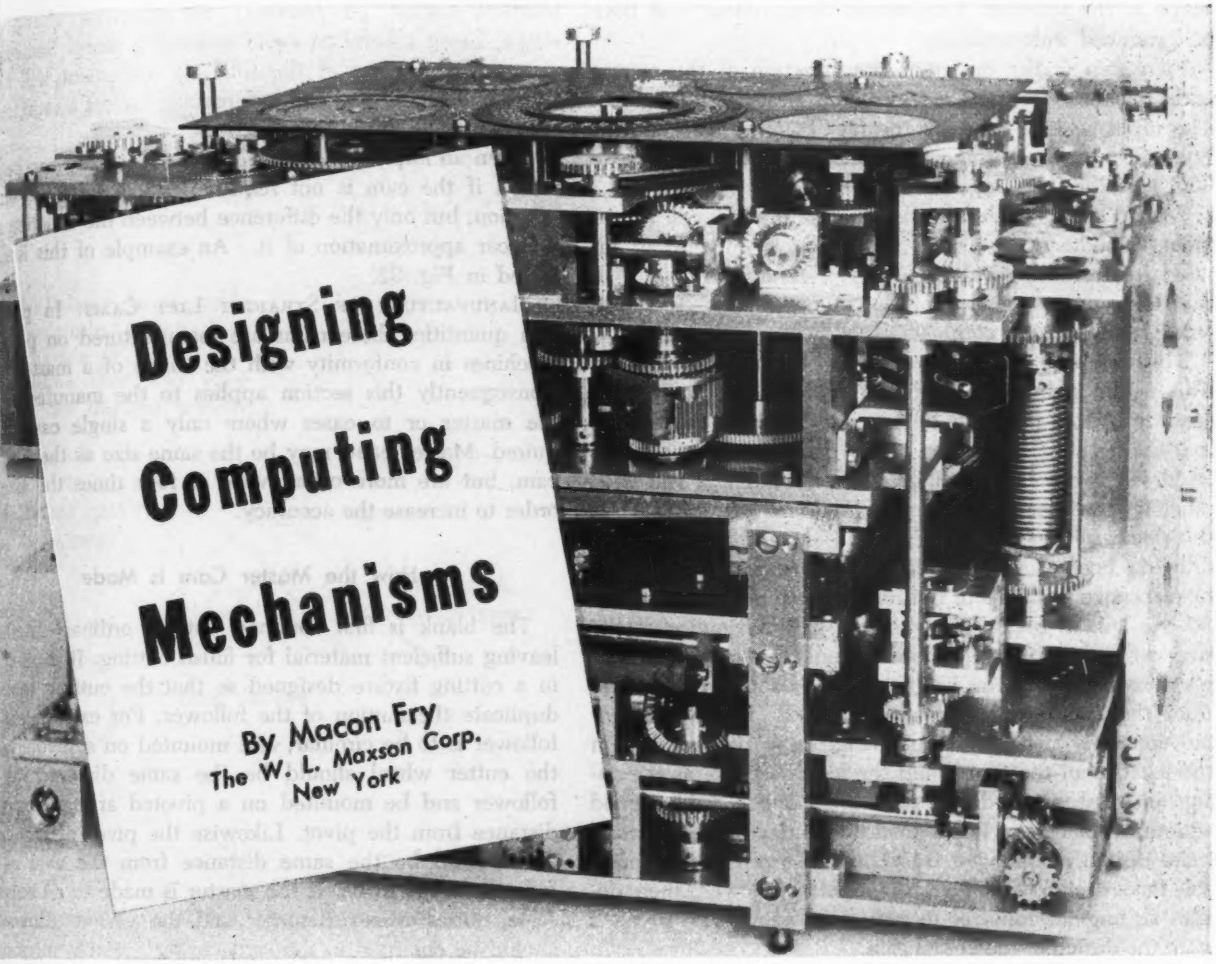
In designing the rotors for the large Lysholm compressors used in this plant, it was necessary to use steel shafts. However, steel was not a suitable material for the rotors themselves, which are cast iron. The problem of attaching the steel shafts into the cast iron rotors was met after some study of alternative methods, by using a low-temperature braze. Although a well known process used extensively on small parts, low-temperature brazing or silver soldering had been little used on such large parts and tests were made to establish the proper placing of brazing material, the method of cleaning and fluxing, and the heating cycle procedure. As a result, good silver joints of predictable strength were obtained.

Stabilizing the Rotors at High Temperature

It has been found on rotors operating at high temperatures that in some cases the rotors will bend at the elevated temperature and straighten out when cooled. This means that a rotor, in perfect balance when cold, will not be in balance at high temperature as a result of such bending. To eliminate the possibility of this phenomenon, the rotor is "heat indicated"— placed in a furnace with the temperature increasing gradually while the rotor is being rotated. As the temperature is increased the amount the rotor bends is gauged by measuring the eccentricity using dial indicators.

When the rotor reaches a point at which there is no increase in bending with increase in temperature, it is considered to have been heat indicated and set in a stable condition; thereafter it will not bend when the temperature is changed. After heat indication the stub shafts of the rotor are finished-machined, and the rotor is ready for installation in the turbine.

Only a few of the design and manufacturing problems encountered in building equipment to operate at exceedingly high temperatures have been discussed. As the temperatures at which gas turbines are to be operated is increased, these problems will become more difficult. However, it is felt that the biggest gap to be bridged has been the building of the first machine, and that the experience gained can be carried over, with slight modifications, to the building of future gas turbine power plants.



Designing Computing Mechanisms

By Macon Fry
The W. L. Maxson Corp.
New York

Part III—Cam Mechanisms

MANY mathematical relationships and functions resist computation by any of the methods discussed in the previous articles of this series. This may be because of their functional nature, or because of mechanical impracticability (as in the case of some trigonometric functions), or because they are purely empirical and exist only as curves or tables. In such cases recourse must be had to cams or similar devices to compute them by "brute force". This method might be called tabular, since it corresponds to looking up a function in a table rather than setting up a mechanical analog of it.

Cam Mechanisms Offer Simple Method

Straight Lift Cams: A straight lift cam is simply a disk shaped in such a way that, when it is moved by the input variable, the motion of a follower will represent the desired function of that variable. The cam may be either rotated or translated, but the former is more common. The follower likewise may either move in guides or rotate. Contacting surface may be flat, circular or occasionally arbitrarily shaped. The shape of the follower surface has considerable effect on the form of the cam, as will be seen shortly. Examples of cams and followers are shown in *Fig.* 29. An excellent type of follower is simply a small ball bearing secured to the output arm. Sharply pointed followers should be avoided, as they tend to "brinell" the surface of the cam under the influence of the return spring, which must be powerful enough to keep the follower in contact with the cam at all times and drive the connected mechanism. Also a pointed follower may gouge the cam if any considerable rise is encountered.

Design of Straight Lift Cams: If the follower were a point and moved radially from the center of the cam, the shape of the cam would be simply a graph of the function in polar co-ordinates. However, since the follower always has a finite size, such a graph really represents the locus of the follower reference point, and the actual cam contour is another curve drawn tangent to the follower surface at every point. This will be made clear by *Fig.* 30, which shows two cams computing the same function but having differently shaped followers. Where the follower rotates as a swinging arm instead of translating radially, the cam contour is still further altered, since the function is the angle taken by the follower, not the radial distance.

In designing a cam, the actual cam contour itself is never calculated. Instead the desired movement of the follower (angular or radial) is tabulated as a function of the input, and the cutting method is designed to reproduce the motion of the follower, using a cutter of the same size and

shape as the follower. The correct cam contour will then be produced automatically.

First step in the design is the selection of the output scale. This is of course fixed by the accuracy requirements. The input scale is fixed by the fact that the cam can rotate, at most, something less than one revolution (say 330°) for the full range of the input.

Second step is to decide the *sense* of the follower movement (whether the follower should move outward or inward for increasing values). This preferably is chosen so that the steepest portion of the function curve is at the outer radius of the cam.

Third step is the selection of the *datum circle* radius. This is the radius at which the follower position represents zero. It is primarily determined by the consideration that the greatest inclination of the cam contour should be under 45° with ball-bearing followers, and less still with other types. Some cut-and-try methods may be required at this point, so the cam should be laid out graphically on the drawing board, drawing the contour as a curve tangent to successive positions of the follower, as illustrated in *Fig.* 30. As a first guess, a few points in the vicinity of the steepest portion of the function should be laid out, using a radius such that the length of arc is somewhat greater than the rise during the same interval. If the follower movement is angular, some change may be required in the location of the center and the length of arm as the design progresses, in order to avoid interference and get good action. In some cases it is a good plan to lay out an approximate design assuming a translated follower, even though the final design will have an angular follower, then design an angular follower to give good action and proceed with the design of the actual cam.

Avoiding Undercut

Fourth step is to check the design against *undercutting*. This occurs whenever the extension of the follower at one point cuts under the contour against which the follower rests when located at another point. This is illustrated in *Fig.* 31. It can be calculated (with circular followers it occurs whenever the convex radius of curvature of the follower locus is less than the radius of the follower), but the easiest way is to lay out the cam carefully on the board and look for it. If undercutting occurs, one remedy is to increase the datum circle or reduce the output scale. If this fails or is undesirable, reduce the follower radius (if circular) or otherwise chang[e] shape, being careful to avoid making it sharp. Some[times] reversing the sense of the follower movement will [help.] By proper juggling of all the foregoing factors a satisf[actory] cam can generally be produced.

Often an improvement in scale and accuracy can b[e ob]tained if the cam is not required to compute the e[ntire] function, but only the difference between the functio[n and] a linear approximation of it. An example of this is i[llus]trated in *Fig.* 32.

MANUFACTURE OF STRAIGHT LIFT CAMS: In pr[oduc]tion quantities these cams are manufactured on pr[ofiling] machines in conformity with the shape of a master [cam.] Consequently this section applies to the manufactu[re of] the master or to cases where only a single cam i[s re]quired. Master cams may be the same size as the fi[nal] cam, but are more often twice or four times the si[ze, in] order to increase the accuracy.

How the Master Cam Is Made

The blank is first roughed out by ordinary meth[ods] leaving sufficient material for finish cutting. It is the[n set] in a cutting fixture designed so that the cutting tool [will] duplicate the motion of the follower. For example, if [the] follower is to be circular, and mounted on a pivoted [arm,] the cutter wheel should be the same diameter as [the] follower and be mounted on a pivoted arm at the s[ame] distance from the pivot. Likewise the pivot of the cu[tter] arm should be the same distance from the cam as [the] follower arm will be. If the master is made to an enla[rged] scale, cutter wheel diameter and the various dimens[ions] should be enlarged in the same scale. Suitable microm[eter] indexing dials and handles should be provided to mea[sure] cam and follower rotation. A table of cam data should [also] be supplied, showing values of follower rotation ag[ainst] corresponding values of cam rotation. The cam is [in]dexed to the starting point, the dials are set with respe[ct to] the datum, and the cutter arm is indexed down to the v[alue] called for in the table. The arm is then lifted, the c[am] indexed to the next point and another cut taken, and [so] on. When the circuit has been made, the cam will ha[ve a] "scalloped" edge with ridges between the successive c[uts] of height depending upon their proximity. For accu[rate] work they should be close enough so that these rid[ges] project perhaps 0.005 to 0.010-in. The cam is now remo[ved] and the periphery coated with Prussian blue. It is th[e]

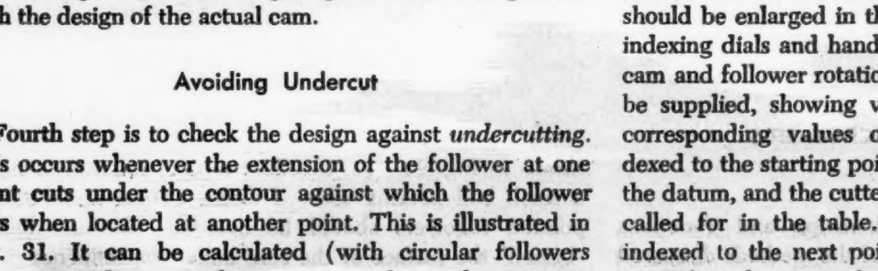
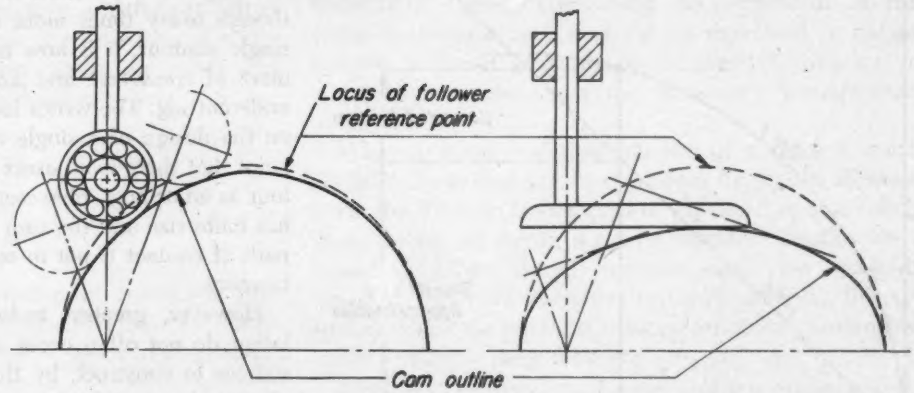
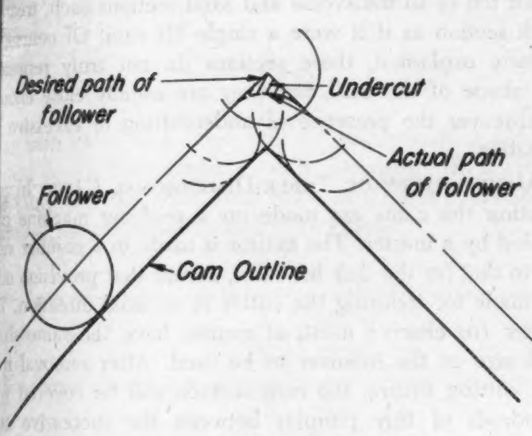


Fig. 29—Types of follo[wers] for straight lift cams used for continuous computing me[ch]anisms. Outer race of [ball] bearing serves as ro[ller] in circular type follo[wers]

30 — Right — Effect of
wer shape on cam out-
Both cams illustrated
pute the same function



31—Below—An example
ndercutting, in which it
impossible to produce a
outline that will give
ower the desired motion



shed by hand until the ridges are removed and a ooth, continuous surface results; this can be judged by gradual disappearance of the blued area. The cam is n replaced in the fixture, a follower substituted for the ting wheel, and a sufficient number of points tested. ne of these points should be selected so as to fall *between* points used in cutting, in order to check the accuracy of e hand filing. It is well to put a reference mark of some t on the cam to indicate the zero or starting point. is is useful both on the master and on the production ms for calibration purposes. This mark can be a hole lled through the blank, which can be lined up (by eans of a setting rod) with similar holes through the unting frame.

Cutter Movement Corresponds to Follower Motion

In the foregoing detailed description a circular follower d angular output were assumed. Analogous procedure uld be used for other types. With a flat follower, for mple, the cutter should be arranged to take a straight t in the plane of the follower for each position.

SPIRAL GROOVE CAMS: In this type of cam the con- ur is cut in the form of a groove in the side of a flat k. It has an advantage over the ordinary lift cam in that e cam can make more than one revolution, thereby per- itting an increase in the scale of the input. In fact the itation to the input scale is determined now by the rmissible proximity of successive grooves. Another vantage is that it can be designed so that the follower s the groove closely, and thus no follower return spring is eded (positive return).

Procedure for designing the spiral groove cam is exactly the same as for the lift cam, except that the follower is always circular, usually a ball bearing. It is cut in a similar way for production, using a master cam and a profiling machine.

Manufacture of the master is somewhat different. One way is to use a series of straight lift masters, one for each revolution (with sufficient overlap) and transfer from one to the other. Another way is to "build up" a master as follows: Holes are drilled at intervals in a disk along a spiral representing the locus of the center of the follower. Studs having the same diameter as the master follower in the profiling machine are then inserted in these holes. A heavy phosphor-bronze wire now is wrapped around the outside of the spiral, touching all the studs, and is firmly soldered to the disk throughout its length. The studs are then removed. In cutting the cams the master follower is pressed tightly against this wire.

Disk Cam Is Most Compact Type

OTHER TYPES OF LIFT CAMS: Cams are sometimes made in the form of rotating cylinders with one end shaped to compute the function. A variation of this is the *barrel cam*, where a spiral is cut in the surface of a cylinder. The design of such cams is not greatly different from the preceding types, a layout being made of the development of the cylinder. These types are seldom used in computing instruments, since economy of space gives the advantage to the disk types.

THREE DIMENSIONAL CAMS: This type of cam, *Fig.* 33, computes any function of two independent variables: $z = f(x,y)$. It differs chiefly from the disk lift cams described previously in that it is shaped both in the peripheral and axial directions, so that rotation of the cam represents one input (x), while axial motion of the follower represents the other (y). Thus the contour of any particular transverse section represents z as a function of x for that particular value of y; or stated another way, successive transverse sections represent a family of curves of z against x for successive values of y. Hence the surface of the cam constitutes a sort of three-dimensional graph of x, y and z in what would be cylindrical co-ordinates if the follower moved radially and had a point contact.

Since this type of cam can be designed for any function of two variables, it can be, and has been, used for multiplying them. However, in view of the other simpler and

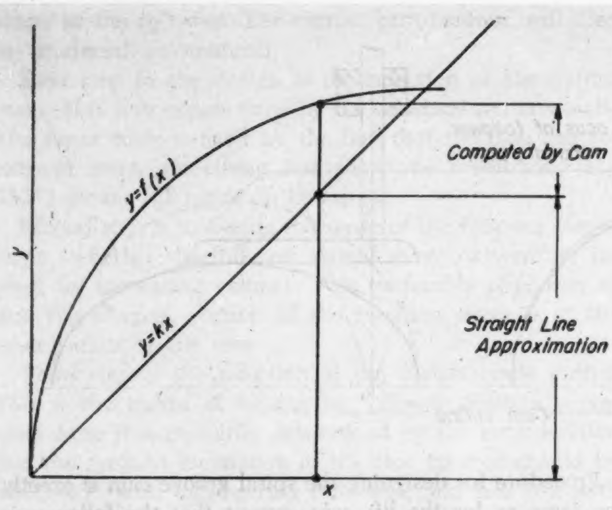


Fig. 32—Use of a straight line approximation to reduce cam rise and improve the scale and accuracy

better types of multiplier available, it has always seemed to the writer that this is doing it the hard way.

Proper employment of this type of cam is in cases where the relationship is so complicated that an anlytical solution would require excessive mechanism, or where no analytical solution exists, the function being known only in the form of tabulated data or curves. An example of such use in fire-control work is the computation of the various exterior ballistic quantities, such as the time of flight of the projectile. For a given projectile and initial velocity, time of flight is a compound function of range and quadrant elevation.

How Three-Dimensional Cam Works

As shown in *Fig.* 33, the follower arm is mounted on a lead-screw which propels it axially. The rotational movement of this arm is transferred by means of a sector to a pinion rod running the full length of the lead screw, so that the sector is engaged at any axial position.

Follower return spring can be a helical or spiral spring placed on the shaft extension of this pinion rod at some convenient place. The follower contact surface is generally spherical, such as a steel ball secured to the end of the arm. A roller is used sometimes, arranged to roll in the direction having the greatest cam inclination. This roller might be spherical also or (if it rolls in the axial direction) could be cylindrical. The latter type would then be equivalent to a flat follower for rotation of the cam and a circular one for axial translation.

The reader may now ask if there is not an error introduced by the lead screw, because as the arm rotates in response to the rise of the cam it will be "fed" along the screw a trifle, thus being at a slightly different axial position from the nominal one set in. Actually no error will normally be introduced, for this effect is automatically corrected by the cam surface itself if the cutter is indexed with the same lead screw as the follower. Even if this correction is absent (due to the use of some other cutting method) the error can still be made negligible by using a sufficiently fine thread on the lead screw, thus reducing the axial movement in relation to the rotation.

Design of these cams is similar to that of lift cams though many times more onerous. Instead of studying a single contour, it is now necessary to examine a score or more of transverse and axial sections for inclination and undercutting. The writer has spent as much as two months on the design of a single cam. It should be noted at this point that there is no exact method for representing a contour as an orthographic section, because, since the follower has finite size and the cam is a warped surface, the actual path of contact is not in one plant but is, in fact, a curve in space.

However, greatest inclinations in rotation and translation do not often occur at the same spots, so it usually suffices to construct, by the methods outlined previously, about ten or so transverse and axial sections each, treating each section as if it were a single lift cam. Of course, as already explained, these sections do not truly represent the shape of the cam, but they are usually close enough to discover the presence of undercutting or excessive inclination.

MANUFACTURE OF THREE-DIMENSIONAL CAMS: In production the cams are made on a profiling machine controlled by a master. The master is made in a manner similar to that for the disk lift cams, except that provision must be made for indexing the cutter in an axial direction. The cutter (or cherry) must, of course, have the same shape and size as the follower to be used. After removal from the cutting fixture, the cam surface will be covered with hundreds of tiny pimples between the successive cuts which must be removed until a perfectly smooth surface results.

This operation of "striking" is a high art with three-dimensional cams; a selection of round files must be on hand, and the proper one chosen to conform more or less with the surface of the cam at the point being filed. After striking, the cam usually is polished to remove file marks. Production cams generally are polished also after they come off the profiling machine.

Masters have also been "built up" by assembling a number of thin disks representing successive transverse sections on a mandrel, and then filling in the spaces between with plaster of Paris and smoothing off by hand. Such a method is fraught with perils, not the least of which is the fact that the whole assembly generally warps as the plaster hardens. However, this technique might answer in some cases.

A Powerful Computing Tool

GEAR CAMS: Gear cams for computing the square have already been discussed in some detail in connection with the Quarter Squares multiplier. They can also be used for many other functions and, in suitable applications, represent the most powerful computing tool we have. This may be seen from the fact that the spiral of a six-inch gear cam will have an average developed length of about 1[illegible] inches. Hence a straight lift cam of equal accuracy would need to have a total rise of over nine feet! Gear cam computers have been made having an accuracy of one part in 30,000.

It has already been seen that the square function gives rise to an Archimedean spiral. The theory for any function

now be illustrated. Let x = angular rotation of disk, r = instantaneous radius of contact, y = angular rotation of output gear, and R = pitch radius of output gear. x and y connected by some function. Since the pitch line speed is the same for both cam and follower gear:

$$r\,dx = R\,dy$$

$$r = R\frac{dy}{dx}$$

Therefore the instantaneous radius of contact is proportional to the first derivative of the function. To obtain co-ordinates of each tooth, let T = tooth number and P = diametral pitch, then

$$y = T\frac{\pi}{PR}$$

For each value of y there will be corresponding values of x and dy/dx, from which r can be obtained. In making a table of x and r for each value of T, it is convenient to arrange the columns somewhat as follows:

T	y	$r\left(=R\frac{dy}{dx}\right)$	x

To speed the calculation it often is more convenient to arrange the relation connecting x and y so that both x and dy/dx are expressed as functions of y. In fact they can be expressed as functions of T, if desired, since y is proportional to T, thereby eliminating one column. In the foregoing derivations both x and y are expressed in radians; actually x would probably be tabulated in degrees and minutes, since those are the customary manufacturing units.

Where y is an analytical function of x, there is usually no difficulty in deriving an expression for dy/dx. However, when the function is empirical or expressed only in tabular form, values of dy/dx must be obtained by the use of numerical differentiation formulas employing finite differences. There are numerous textbooks covering this subject, to which the reader is referred for specific information on how to apply these formulas[4].

Offset Follower: In the study of the squaring unit it

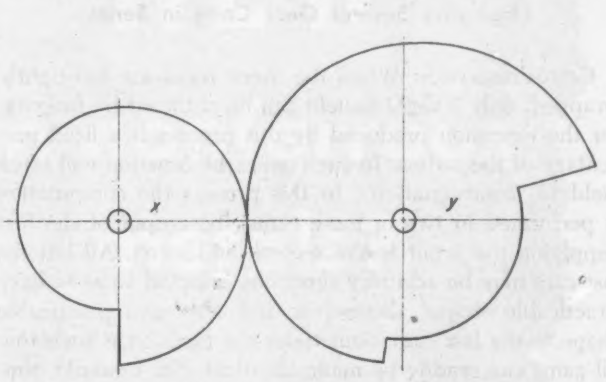


Fig. 34—Tape wheels or noncircular gears, in which rolling contact is maintained between the pitch surfaces

was shown that by offsetting the follower from the center of the disk an amount equal to the lead per radian, the plane of the follower could be made tangent to the spiral at all points. Of course this is valid only for the square, since it is the only function which gives rise to a constant lead for the spiral. For any other function it would be necessary to vary the offset, which is, of course, not mechanically practicable. However, the greatest inclination of the spiral to the follower plane generally occurs near the center, so if the offset is made equal to the instantaneous lead, dr/dx, when the radius is least, satisfactory operation generally will be obtained. Since

$$r = R\frac{dy}{dx}$$

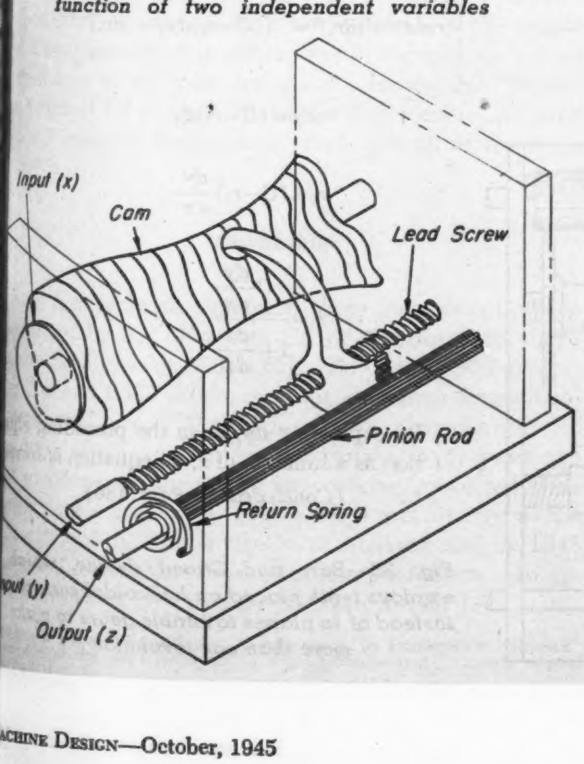
$$\frac{dr}{dx} = R\frac{d^2y}{dx^2}$$

Evaluating this expression for the inner radius of the spiral will give the correct offset.

Limitation of Gear Cam Designs: A limitation of the gear cam occurs when successive turns of the spiral are so tightly wrapped that there is insufficient clearance for the follower and its guide shoe. This condition prevails when there is a great change in lead through the range of the function. When the lead at the outer radius is less than at the inner, the outer turns are more tightly wrapped, and vice-versa. Of the two cases, small inner lead gives the greater difficulty. For cams of moderate (6-inch) size,

[4] See, for example, "Numerical Mathematical Analysis" by J. B. Scarborough, Johns Hopkins Press, 1930, Pages 114-117.

Fig. 33—Three-dimensional cam, for computing any function of two independent variables



the feasible limit of the ratio of outer to inner lead is in the neighborhood of ten to one.

FUDGING: When the outer turns are too tightly wrapped, some improvement can be obtained by a process known as "fudging". This consists of arbitrarily extending the radius beyond the normal value, although keeping the same angular spacing between teeth. Since this produces an increase in the circular pitch, the pressure angle of the conical teeth must be increased to correspond[5]. The practical limit of this technique is an increase of radius of about 5 to 10 per cent. It should be observed that the action is correct in every way; the only change is a progressive increase in circular pitch, accompanied by a corresponding increase in pressure angle.

Employing Several Gear Cams in Series

CONCATENATION: When the inner turns are too tightly wrapped, only a slight benefit can be obtained by fudging, for the extension produced by this process is a fixed percentage of the radius. In such cases the function will often yield to "concatenation". In this process the computation is performed in two or more cams, the output of the first supplying the input to the second, and so on. All but the last cam may be arbitrary functions, selected so as to have practicable shapes themselves and also give practicable shape to the last cam. Sometimes the function is such that all cams can readily be made identical. For example, suppose the function to be

$$y=x^8=[(x^2)^2]^2$$

The function obviously can be calculated by concatenating three squaring cams. Indeed, it can be shown that it is possible to split any function into any number of identical concatenated functions, but it is a mathematical *tour de force* to evaluate these for any but the most elementary functions.

TAPE-WHEELS: These consist essentially of two noncircular cylinders in rolling contact at a fixed center distance, *Fig.* 34. They are shaped so that when the driver is positioned to represent an input quantity, x, the driven cylinder will take a position to represent some desired function $y=f(x)$. To insure that no slipping occurs, crossed tapes are passed from one wheel to the other, being secured at some convenient place on the periphery of each. Thus the movement of one wheel is transmitted to the other positively by belt tension rather than by friction at the point of contact.

Shapes of these wheels may be determined as follows: Let x = angular rotation of driving wheel, r_1 = radius to point of contact on driving wheel, y = angular rotation of driven wheel, r_2 = radius to point of contact on driven wheel, and C = distance between centers of rotation of wheels. x and y are connected by some function. If the point of contact is to be on the line of centers, then:

$$r_1+r_2=C$$

Since the peripheral motions of the two wheels must be equal at all points:

$$\sqrt{(r_1dx)^2+(dr_1)^2}=\sqrt{(r_2dy)^2+(dr_2)^2}$$

but

$$r_2=C-r_1$$

and

$$dr_2=-dr_1$$

therefore

$$\sqrt{(r_1dx)^2+(dr_1)^2}=\sqrt{[(C-r_1)dy]^2+(-dr_1)^2}$$

$$(r_1dx)^2+(dr_1)^2=[(C-r_1)dy]^2+(dr_1)^2$$

$$r_1dx=(C-r_1)dy$$

$$r_1=(C-r_1)\frac{dy}{dx}$$

$$r_1=\frac{C\dfrac{dy}{dx}}{1+\dfrac{dy}{dx}}$$

By expressing dy/dx in the preceding equation as a function of x, an equation is formed

(*Concluded on Page* 186)

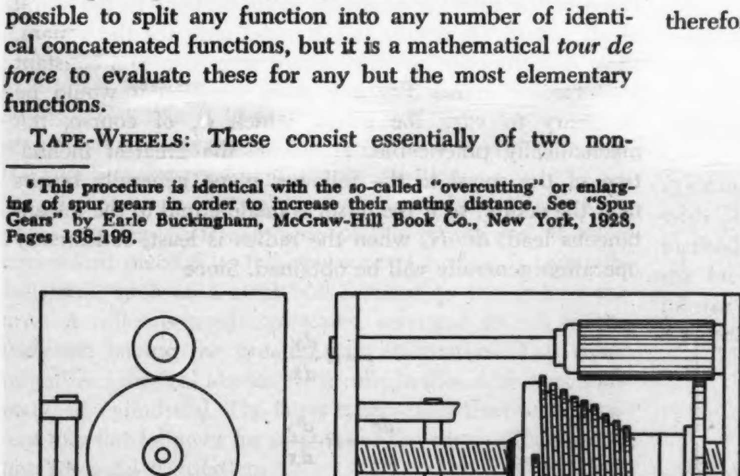


Fig. 35—Barr and Stroud device, which employs teeth placed on helicoidal surfaces instead of in planes to enable gears to make more than one revolution

[5] **This procedure is identical with the so-called "overcutting" or enlarging of spur gears in order to increase their mating distance. See "Spur Gears" by Earle Buckingham, McGraw-Hill Book Co., New York, 1928, Pages 138-199.**

WHAT'S NEW in nonferrous metals?

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NOW that war shortages have virtual- passed into history, we may expect to see ensive jockeying for position on the part the producers of widely different mate- ls. No longer does the designer accept field as apportioned off to one mate- l or another. Steel, aluminum, mag- sium, zinc, copper, nickel, wood, and a g list of synthetics have all become ect competitors in many cases. In some tances the substitutions have come to y because of unexpected advantages but others reversion to time-tried materials ll result. Some alternatives are thorough- satisfactory, deserving equal considera- n with the previously used material.

The designer should survey the materials the past decade with great care. To let decision be guided by past custom may prove fatal if competitor is first to appreciate the advantages of me new or improved material. This review, which will scuss only nonferrous metal developments of the last ten ars, was inspired by appreciation of the necessity for owing at least something about these recent changes in e kaleidoscopic materials picture. It would be imprac- able to cover in complete detail every one of the impor- nt developments that either was introduced or gained ominence in the past ten years. Hence this "digest" s planned for the benefit of those engineers whose work d not brought them into contact with all of the items vered.

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Aluminum

New high-strength aluminum alloys have recently been nounced by the Aluminum Co. of America (75S alloy) d by the Reynolds Metals Co., (R301 and R303 alloys). he 75S and R303 alloys are of the aluminum-magnesium- nc-copper type. The high-strength characteristics of is type of composition was recognized many years ago t problems of stress-corrosion-cracking prevented their rlier development. By 1939 success was attained in the boratory of the Aluminum Co. of America, and by 1943 e new 75S composition was put into production. An ap- lication of this type of alloy is shown in *Fig.* 1.

From a paper "Some Recent Developments in Engineering Materials" esented at the 1944 American Society of Mechanical Engineers annual eeting.

The exact composition of these alloys is still withheld from publication, but figures on their physical properties have been released. They show ultimate tensile strengths ranging from over 70,000 to 88,000 psi, depending upon the heat treatment, aging, and also the amount of prior working. Yield strengths are also high, ranging from 69,-000 to 82,000 psi with elongation between 9 and 11 per cent. Both alloys are available as clad sheets as well as in the unclad form. Modulus of elasticity is 10,300,000 psi, and the specific gravity is between 2.82 and 2.83. Resistance to corrosion compares favorably with that of older high-strength aluminum alloys, exceeding slightly that of bare 24S-T.

The R301 alloy offered by Reynolds differs slightly from 14S and 24S in composition but is clad with a high-strength low-corrosion alloy. This sheet has excellent forming properties and develops 59,000 to 69,000 psi, depending upon the aging treatment used. The cladding is a magnesium-silicide-type alloy and is both highly resistant to corrosion and anodic to the base metal, affording electrolytic protection.

Considerable work has also been done on the effect of aging 24S-T alloy at elevated temperatures after varying amounts of strain hardening by either rolling or stretching. As a result, it has been found possible to increase the ultimate tensile strength of clad 24S-T sheet by a few thousand pounds per square inch, but the yield strength may be increased by upward of 20,000 psi.

Although not a new development, the vast extension of the use of refrigeration of heat-treated aluminum in recent

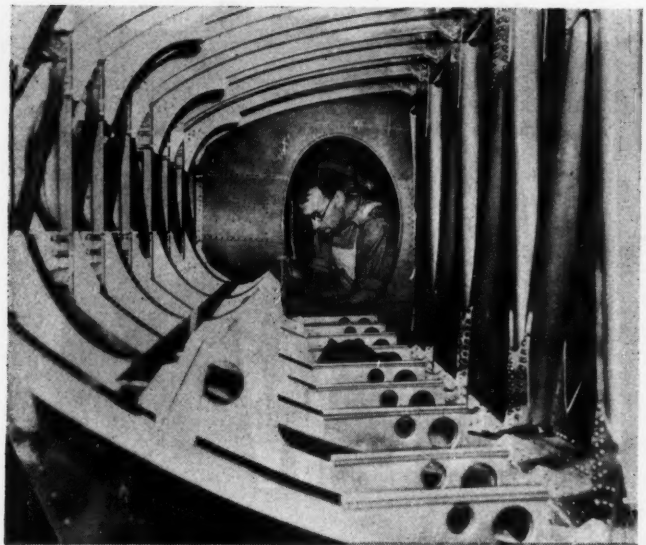


Fig. 1—Interior view of outer wing panel of a plane. Extruded shapes are 75S aluminum and sheet is 24S

years warrants mention. As is well known, many aluminum alloys age harden at room temperatures after the heat treatment. For a relatively short time after the heat treatment (a few hours for 17S and 24S), they are still relatively soft and may be cold worked. After this, rivets become too hard to drive without cracking. Advantage has been taken of this fact in the use of aluminum-alloy rivets which are usually heat treated and then driven, after which they age harden as a result of the heat treatment given them.

High coefficient of thermal expansion has always been one of the outstanding characteristics of aluminum alloys. It is thus of interest to note that some new aluminum alloys such as Vanasil have been produced with coefficients of thermal expansion very close to that of cast iron.

This alloy contains a total of 21 to 23 per cent of silicon, and its manufacture requires the compounding of a hypereutectic alloy of aluminum and silicon to which copper, magnesium, and nickel are added. The specific gravity is 2.62, as compared with 2.70 for aluminum, and 2.63 to 2.94 for the general range of cast aluminum alloys. The tensile strength of this new alloy is 32,400 psi at room temperature, 30,300 psi at 300 F, and 23,150 psi at 500 F, thus showing what is for an aluminum alloy unusual ability to retain its strength at elevated temperatures. Its hardness is 100 to 160 brinell at room temperature, and (as might be expected from the figures on strength) it retains its hardness well at elevated temperatures. Thermal conductivity is 0.3 to 0.35 cgs units or about 3 times that of cast iron. No permanent growth in volume at high temperature has been observed. The coefficient of friction of Vanasil against cast iron at 158 F has been found to be about 69 per cent of that of typical aluminum piston alloys under similar conditions of test. The modulus of elasticity is 15,000,000, substantially above that of aluminum. Vanasil was developed on the West Coast about 4 years ago and is now being marketed by the Howell Engineering Co., New York.

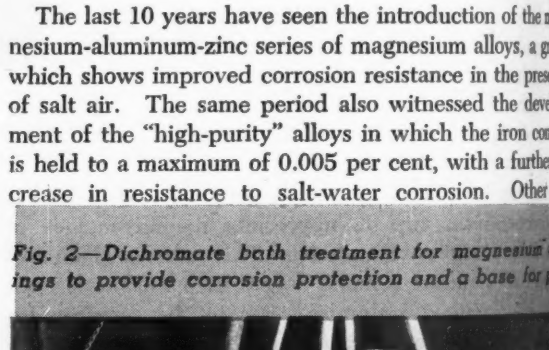
Aluminum bonded to steel was announced early in 1944, by the Al-Fin Corp. of New York, a firm associated with the Fairchild Aviation group. The process involves the casting of an aluminum case on a steel part. Basically the process is one of casting aluminum around a steel insert, resulting in an intermetallic compound of iron and aluminum at the interface, which serves to bond the metals solidly together in much the same manner as a welded or brazed joint. Applications include aluminum fins on steel cylinders of aircraft engines, aluminum-lined steel bearings, brake drums, radiators, etc.

Regarded for many years as "unplatable" by the electroplaters, aluminum is now being plated with nickel, chromium, cadmium, copper, zinc, silver, gold, and brass. The process was originally introduced early in the 19[illegible] and is based on the creation of an anodic film on the surface of the aluminum before plating. The film is then treated with an acid or alkaline solution to render it capable of "taking" the plating. Among other applications this method is being used to plate brass on aluminum to provide adherence of molded rubber to the surface, since rubber will adhere to the brass but not to the aluminum. Another application is on aluminum condenser plates which are nickel-plated to facilitate soldering. Adhesion of the plating to the aluminum is claimed to be equal to that attained with certain other metals and better than zinc on steel.

Magnesium

The last 10 years have seen the introduction of the magnesium-aluminum-zinc series of magnesium alloys, a group which shows improved corrosion resistance in the presence of salt air. The same period also witnessed the development of the "high-purity" alloys in which the iron content is held to a maximum of 0.005 per cent, with a further increase in resistance to salt-water corrosion. Other

Fig. 2—Dichromate bath treatment for magnesium castings to provide corrosion protection and a base for p[illegible]

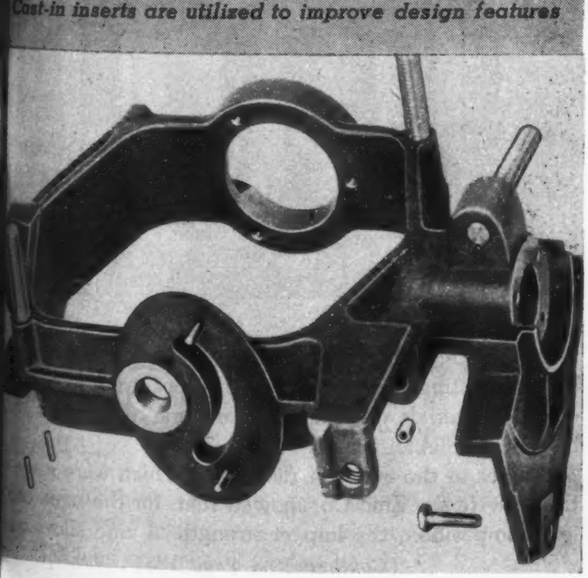


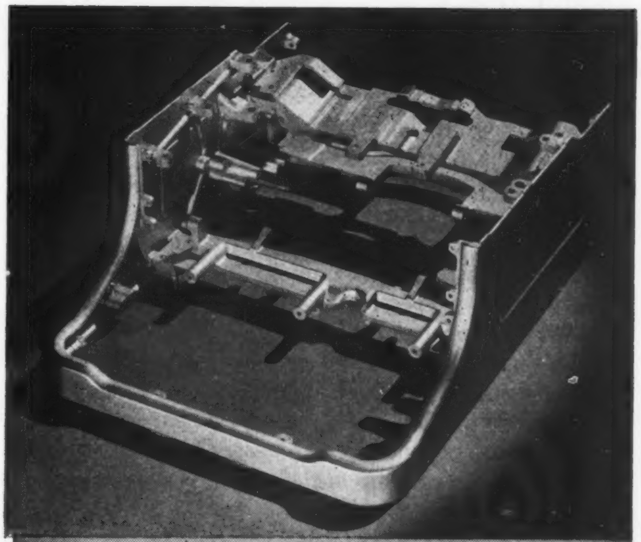
es in the magnesium-alloy field took the form of fab-ing technique, and the development of vastly im-ed welding processes which have made it possible to y magnesium to purposes for which it could not have considered at one time. Of these improved prac-, the most important is undoubtedly the application of um arc welding which eliminates all need for a flux has made the welding of magnesium as simple as that elding steel. These developments have combined to ease enormously the use of magnesium-alloy sheet, ings, and extruded shapes in aircraft, since they have additional advantage of extreme low weight, their cific gravity being 1.76 to 1.83 as against 2.79 for alu-um alloys of the 17S type. Typical of the newer mag-ium alloys is Dow 0-1 which contains 8.5 per cent alu-um, 0.2 per cent manganese, and 0.5 per cent zinc. tensile strength is about 42,000 psi with 5 per cent gation; since this alloy has a specific gravity of only 0 it shows up well in strength-weight ratio, being com-able with 17S aluminum alloy. The modulus of elas-ty of magnesium alloys ranges from 6,200,000 to 6,-,000 psi.

When magnesium alloys first came into use, consider-e trouble was experienced with corrosion, especially in presence of salt water or moist salt air. Under these ditions, unprotected magnesium alloys behave some-at similar to and somewhat worse than unprotected alu-num alloys. Investigation was made of the possibilities surface treatment, in the hope of developing a process alleling that of anodic finishes for aluminum and alu-num alloys. Out of this investigation came four proc-es which have accomplished much in improving the rosion resistance of these alloys. One is the "chrome-kle" treatment, which is suitable mainly for protection parts during storage and shipment. Due to removal of tal in the pickling, this process should not be used ere close dimensions must be held.

More effective protection is attained by the use of the ichromate" treatment, *Fig.* 2, which gives considerable erent protection to the base metal and also serves as an cellent base for such type of paint coating as may be

g. 3—Magnesium die-cast gimbel for an automatic pilot. Cast-in inserts are utilized to improve design features





ig. 4—Aluminum typewriter frame showing the intricate precision details possible by die casting

used to complete the protection. The dichromate treatment is not recommended for the manganese-magnesium type of alloy.

A third process, the "sealed chrome pickle", also in use is simply a variation of the first. This process provides good protection, but as a result of removal of metal in pickling it is not suitable where close dimensional tolerances must be held. All of these processes depend for their effectiveness upon the creation of a surface coat of magnesium chromate.

Still another process, galvanic anodizing, is in use. This process results in a gray to black coat of chromic-magnesium oxide and is recommended for manganese-magnesium alloys where close dimensional tolerances are required.

Beryllium

Extensive use of beryllium has been made only within the past ten years. Its chief use at present is in the manufacture of beryllium copper, but the oxide finds important applications in fluorescent lamps, X-ray windows, and cathode-ray tubes, where use is made of its characteristic of transforming short-wave rays to visible light. Considerable research on the metallurgy of beryllium has been conducted within the last twenty years, particularly in Germany and the United States.

Beryllium has the property of imparting to several metals the ability to respond to heat treatment. This list includes copper, iron, lead, nickel, and silver. However, commercial development has been confined mainly to beryllium copper, because the high cost of the beryllium (about \$15 to \$17 per pound on the basis of the content of master alloys) has limited its use to cases where cheaper elements could not be used to attain adequate results.

Several firms are now producing copper alloys containing around 2 per cent of beryllium and, in some cases, other elements. These alloys are capable of showing substantial improvement in tensile strength and substantial increase in electrical conductivity, as well as the most unusual result of some increase in modulus of elasticity after

suitable heat treatment.

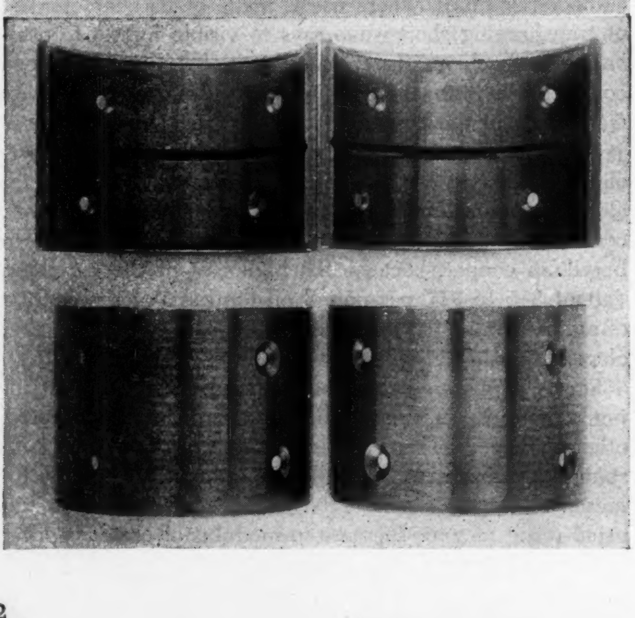
Experimental work has also been carried out on alloys of beryllium and aluminum with the expectation of producing a high-strength lightweight alloy that would exceed the performance of present aluminum alloys. While some success has been attained in this effort, the results have not yet been sufficient to permit commercial competition with the better known aluminum alloys. The outstanding feature of these beryllium-aluminum alloys is their high modulus of elasticity. "Beralite", an alloy consisting of about 35 per cent beryllium, shows a value for E of 21,500,000, as compared with figures around 10,300,000 for various aluminum alloys. Tensile strength approximates that of the strongest of the aluminum alloys, while specific weight is appreciably lower. Development of this alloy is seriously handicapped by the present high cost of beryllium but any radical drop in the cost of beryllium production might open up a market.

Cemented Carbide

Basically, cemented carbide begins with heating of powdered tungsten and carbon (at about 2650 F), which thus unite to form tungsten-carbide particles. The powdered carbides are then mixed with powdered cobalt, pressed into molds and semisintered to cement the hard carbide particles into a coherent metal having a hardness approaching that of the diamond. This material is machined, ground, or otherwise formed and then fully sintered. By varying the amount of cobalt, varying degrees of hardness and toughness are attained; the greater the amount of cobalt, the less the hardness and the higher the toughness. This original development was later extended by the addition of tantalum and titanium carbides to provide special characteristics to meet varying requirements. A line of cemented carbides is now available, varying slightly in individual characteristics, but all showing the following general properties:

1. Extreme hardness, approaching that of the diamond
2. High red hardness

Fig. 5—Copper-silver-lead bearing metal gives several times the life of ordinary copper-lead bearings in heavy-duty Ford truck and bus engines



3. High compressive strength
4. Relatively low resistance to impact
5. High wear resistance
6. High resistance to many forms of corrosion.

Cemented carbides also have been widely used in applications where exceptional wear resistance or sion resistance is required.

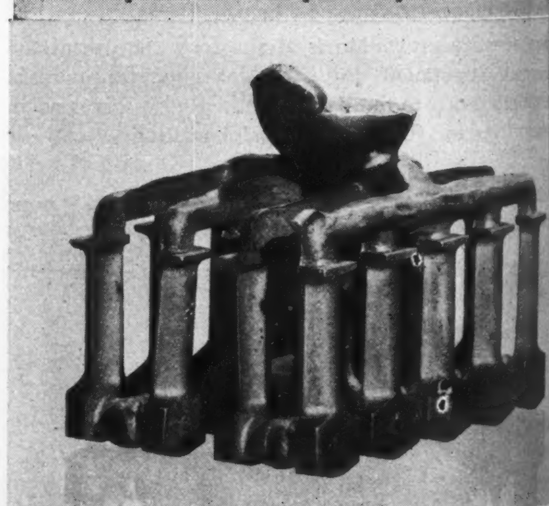
Porous-Chromium Surfacing

The extremely hard and excellent wear-resisting properties of chromium have long been known. This element has one of the lowest coefficients of friction of any metallic elements and, in many cases, has been operated under light load without any lubrication whatsoever. Hard-chromium plating is rated on the Moh scale against 10 for the diamond. On the other hand, smooth chromium has the serious disadvantage of not retaining a good oil film. The Van Der Horst Corp. America is responsible for a novel departure in the application of chromium to bearing surfaces. The finished plate is relatively thick, ranging up to 0.030-in. It has a smooth, hard surface with innumerable microscopic crevices which serve the purpose of retaining the lubricating oil. This finish has been extensively applied to internal combustion-engine cylinder walls, piston rings, etc.

Die-Casting Materials

Advances in die casting have taken the form of improved alloys, improvement in physical properties of castings of the same alloys by better knowledge of die design,

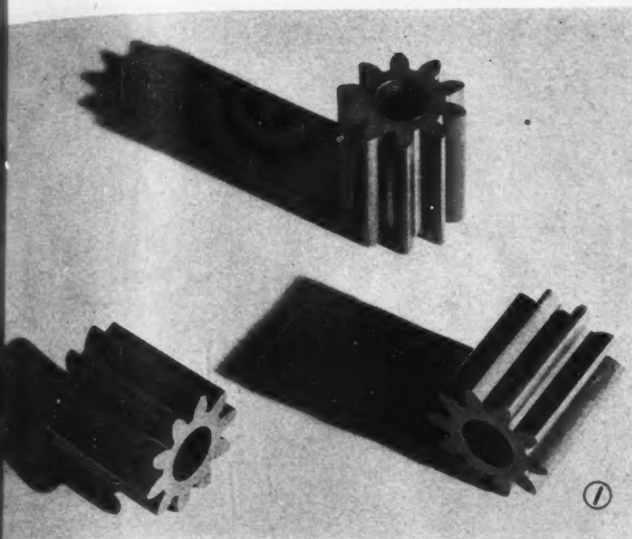
Fig. 6—Supercharger turbine buckets precision from a high-heat-strength alloy of cobalt, chromium and molybdenum. The parts require no machining

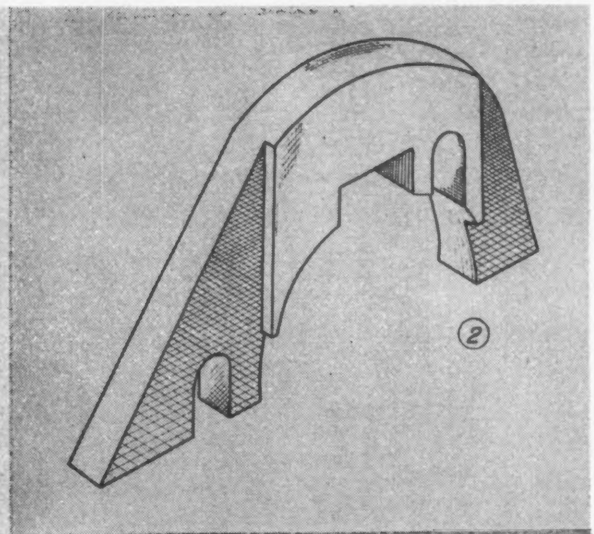


improved physical properties for the same alloys by increased casting pressures. A fairly recent addition to die casting materials was made when some magnesium alloys became available, *Fig.* 3.

Studies of the effect of die design which were made by the New Jersey Zinc Co. showed that, for the same chemical composition, the impact strength of zinc alloys could

(*Continued on Page* 188)





Powder Metal Machine Parts

POWDER metallurgy dates back to the days of the ancient Egyptians who, according to record, reduced original friable iron ore powders into a fused, spongy ss and hammered it into the shapes of the various im-ments of that day.

rom then until the early years of our century progress powder metallurgy remained, for all practical purposes, mant. Since the early 1920's, however, advancement been extremely rapid until today there is no segment our machine building industries that does not offer op-tunities for the advantageous application of powder tal parts.

There are of course many standard stock items made of wder metal which have been old friends of designers some time. These include ready-to-install oil-impreg-ed sleeve bearings, cored and bar stock, and plates and ps. This presentation, however, is more directly con-ned with emphasizing the custom-made parts—those duced to the customer's specifications—and pointing the advantages offered by powder metals in such ap-cations.

In general, it may be stated that the employment of wder metallurgy for machine parts results in the follow-:

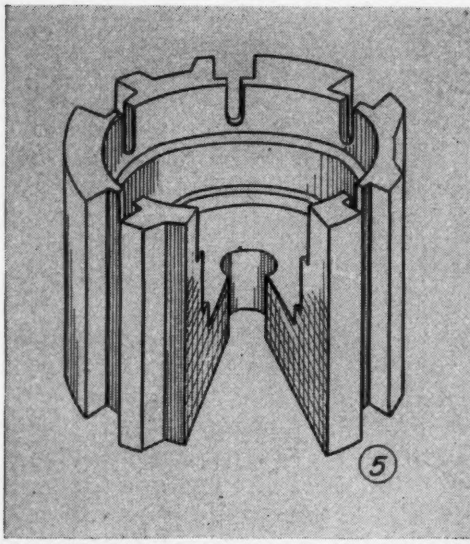
1. Low cost
2. Reduction or elimination of requisite machining and scrapped metal
3. Self-lubrication where needed

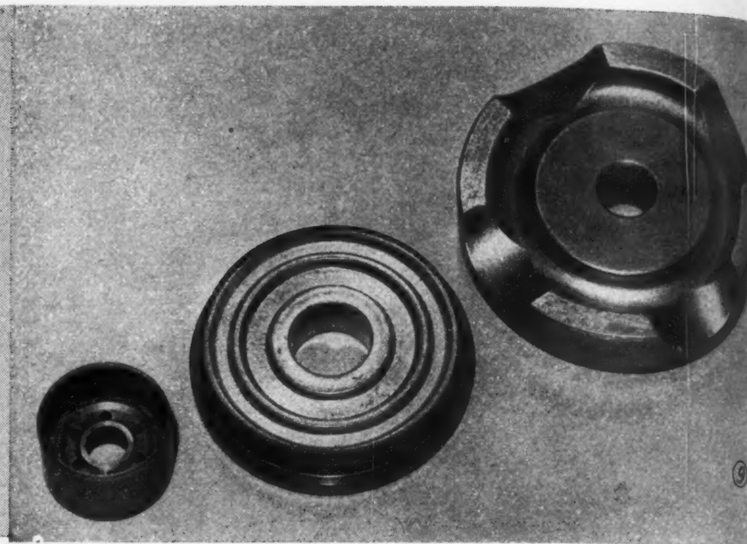
1—Powder metal gears, ferrous or non-ferrous, are accurate in shape, offer excellent wear resistance and, when oil impregnated, are self-lubricating

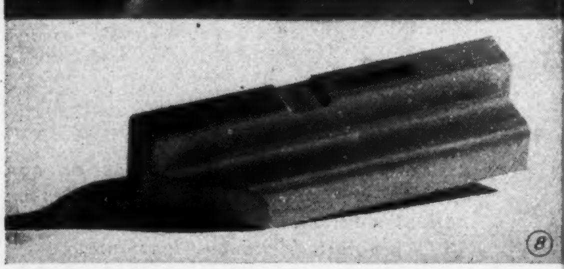
2—Cam of medium-carbon steel has a hardness of about 40 rockwell C. This is an excellent example of a part on which considerable machining was eliminated

3—Set of pump parts produced complete as shown from an iron-copper powder compound. Parts are self-lubricating and require only few seconds to briquette

4—Powder-iron pole pieces such as part shown—suitable for d-c aircraft accessory motors—offer good magnetic qualities, increased ease and speed of manufacture







5—Selector drum of oil-impregnated porous bronze. Tolerances are: 0.001-inch on inside diameter of bore, plus or minus 0.002-inch on counterbore depth, and 0.001-inch on outside slot widths

6—Mating units for army equipment. Manufacturing time, exclusive of sintering, is less than a minute

7—A few of the many different types of electrical contacts that are being made of powder metal

8—Parts such as this height gage base can be produced by powder metallurgy from ferrous powder with high surface hardnesses

9—Ferrous-base parts produced complete without machining. Units are used in army equipment

4. Metallurgical and mechanical uniformity
5. Chemical purity of metal and alloy
6. Ability to hold close dimensional tolerances, smoothness of surfaces
7. Freedom from blowholes, cracks and other defe
8. Comparatively short tool-up period.

First step in the production of a powder me machine part is the blending of the powders pre ously selected as being best suited for the applic tion. Next the powders are pressed or "briquette in a die to the shape of the part. This part is know as a "green compact" and its strength is deriv solely from the interlocking of irregularly shaped pa ticles during compression. Third step is the "sint ing" of the green compact in a furnace having co trolled atmosphere and temperature. The heat e ployed in sintering does not actually melt the po ders in the compact. Instead, it welds the powde together at the surfaces of the particles, serving bond the part into a structure of controlled porosi Last step for highly accurate parts is sizing, whi subjects the parts to pressure in precision dies correct for any expansion or shrinkage that occ during sintering.

Process Saves Materials

It will be apparent that where powder metallur is applicable on mass-produced parts, savings can considerable not only in machining costs but in ma terials as well. Pointing up this fact is an experi ence recently revealed involving a piece of w equipment that required 106 parts per set. In pr ducing 20,000 sets, a saving of 5,000,000 hours a 1,250,000 pounds of strategic materials was effecte as compared with former methods which entailed considerable amount of machining.

Only a brief perusal of the variety of parts p tured on these pages will serve to indicate the ex

which machining has been obviated. However, is well to bear in mind that powder metallurgy will t do away with the need for machine tools. It ould, rather, be appraised as a welcome adjunct the other methods of parts fabrication.

Often parts can be made via powder metallurgy at are either impossible or uneconomical to proce by other methods. An example would be a nge bearing having a spline on its outside diamr extending the full depth to the flange. Again, egularly shaped blind holes or depressions in parts "naturals" for powder metallurgy but otherwise ficult to produce.

Porosity Affects Strength

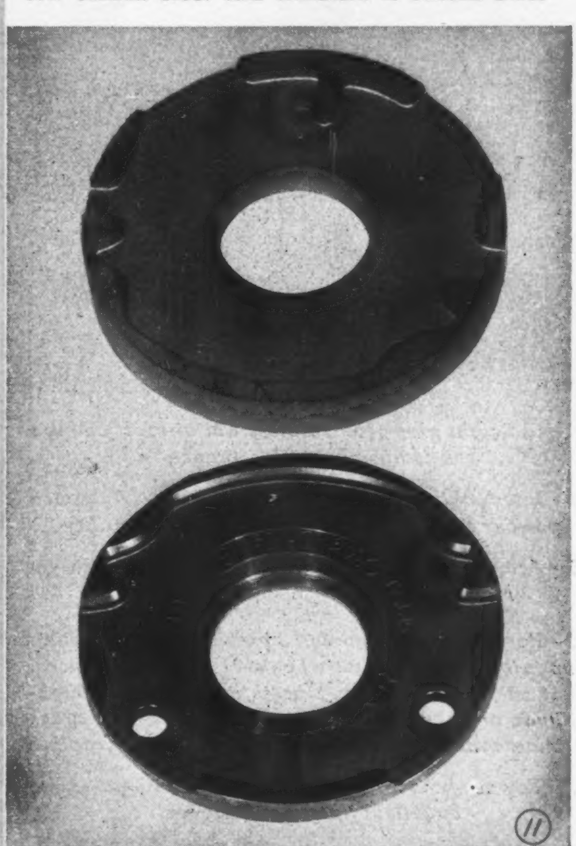
Powder metal machine parts can be made to meet h strength requirements through the use of the oper degree of porosity in their structures. In neral, the less porous a part is the stronger it will , and it is interesting to note that parts having der 1 per cent porosity have been produced in the oratory with tensile strengths up to 166,000 psi. ere is little doubt but that additional research and velopment will raise this figure still further.

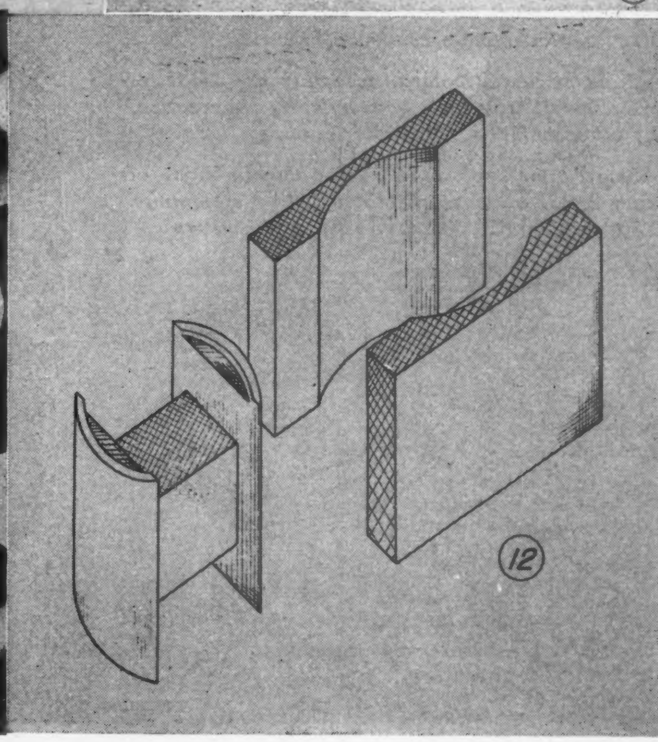
Regarding surface hardness—a requisite for parts at must have high wear resistance—experience ined during the war in the production of V-blocks, crometer frames, plug gages, etc., points the way successful applications of powder metal in many tual operating parts for machines in which wear is primary factor. These V-blocks and other parts entioned, were made from steel-mill scale—a ma-

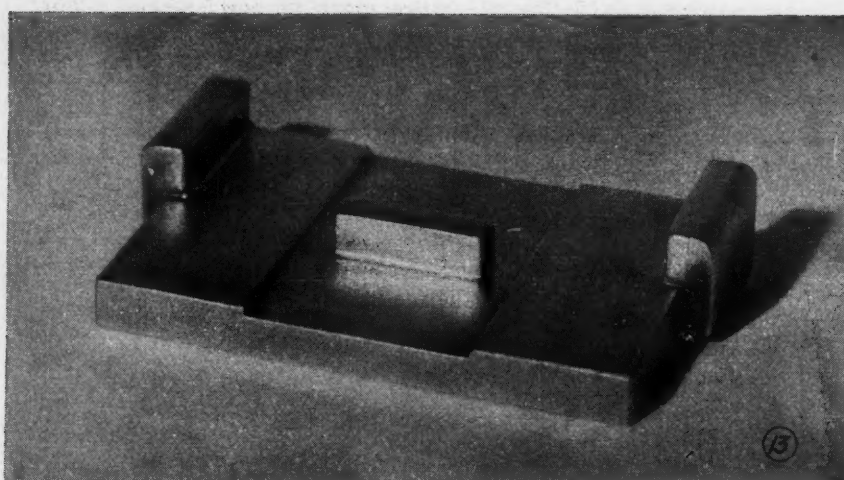
10—Representative group of powder-metal filters. Units such as these are used for filtering, breathing, diffusing, separating, controlling, metering, etc.

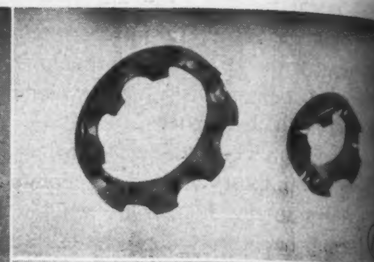
11—Fire cut-off cam made from ferrous powder, oil impregnated. Upper view shows part as briquetted and sized. Lower shows part after machining

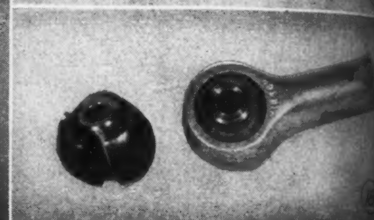
12—Two pole pieces and armature. Pole pieces are low carbon steel and armature is silicon steel

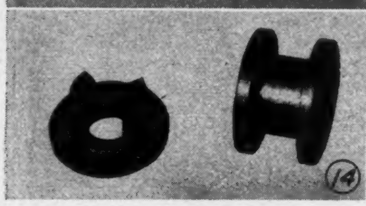


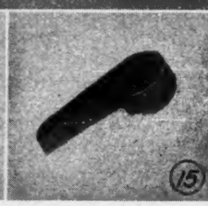












13—Gunsight piece for a Bofors antiaircraft cannon is made of powder bronze

14—Interlocking bearing for lever arm. A bronze powder product, its parts have good ductility

15—Arm of powder brass has good strength—is made complete in one operation

16—Part at left is porous bronze, self-lubricating flange bearing used on wheels of industrial trucks. That at right is bearing used on shutter of high-altitude aerial camera and is made of powder brass mixture containing high percentage of fine graphite

17—Powder-bronze ball bearing retainers have excellent bearing surfaces.

18—Powder bronze aircraft rod-end bearing. Design replaces more costly ball bearing

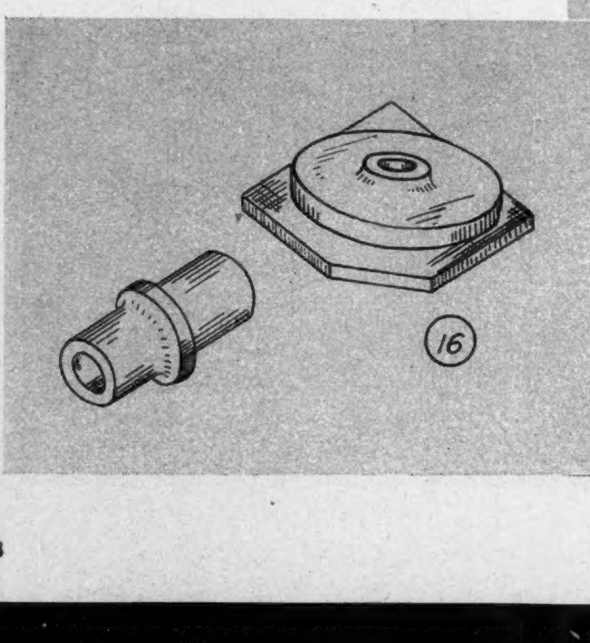
19—Parts of this structural assembly are ideal for powder metallurgy but economically impractical by other methods. Material is powder bronze

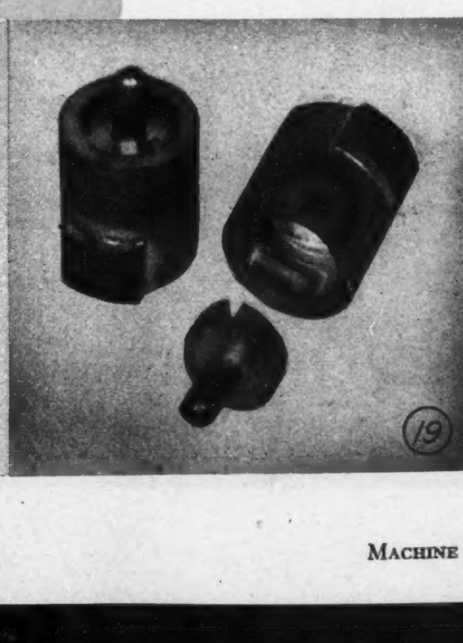
20—Small arms such as this often can be made of powder metal at less cost than drilled stampings. Powder bronze is used for part shown

terial which otherwise would be thrown out as waste—pulverized and reduced at 700 to 1000 C. The surface hardness of such parts, 60 to 65 rockwell C, is sufficient to assure good wearing properties and long life.

As with all other processes, powder metallurgy has limitations as well as advantages. These limitations are due to (1) Lack of good plastic flow in the powders under pressure, (2) friction created by the powders against the walls of the briquetting-die cavities and (3) mechanical limitations of the tools and dies. However, with a proper understanding of the design limitations imposed by these factors, as the illustrations on these pages clearly show, a wide variety of complex shapes can be and are being successfully produced.

MACHINE DESIGN is pleased to acknowledge the collaboration of the following companies both in supplying much of the information that appears in this article and in furnishing the illustrations: American Electro Metal Corp.; Bound Brook Oil-less Bearing Co.; Chrysler Corp., Amplex Division; General Motors Corp., Moraine Products Division; Keystone Carbon Co. Inc.; P. R. Mallory & Co. Inc.





INDUSTRIAL GLASS...

for Special Design Problems

By J. R. Blizard
Corning Glass Works

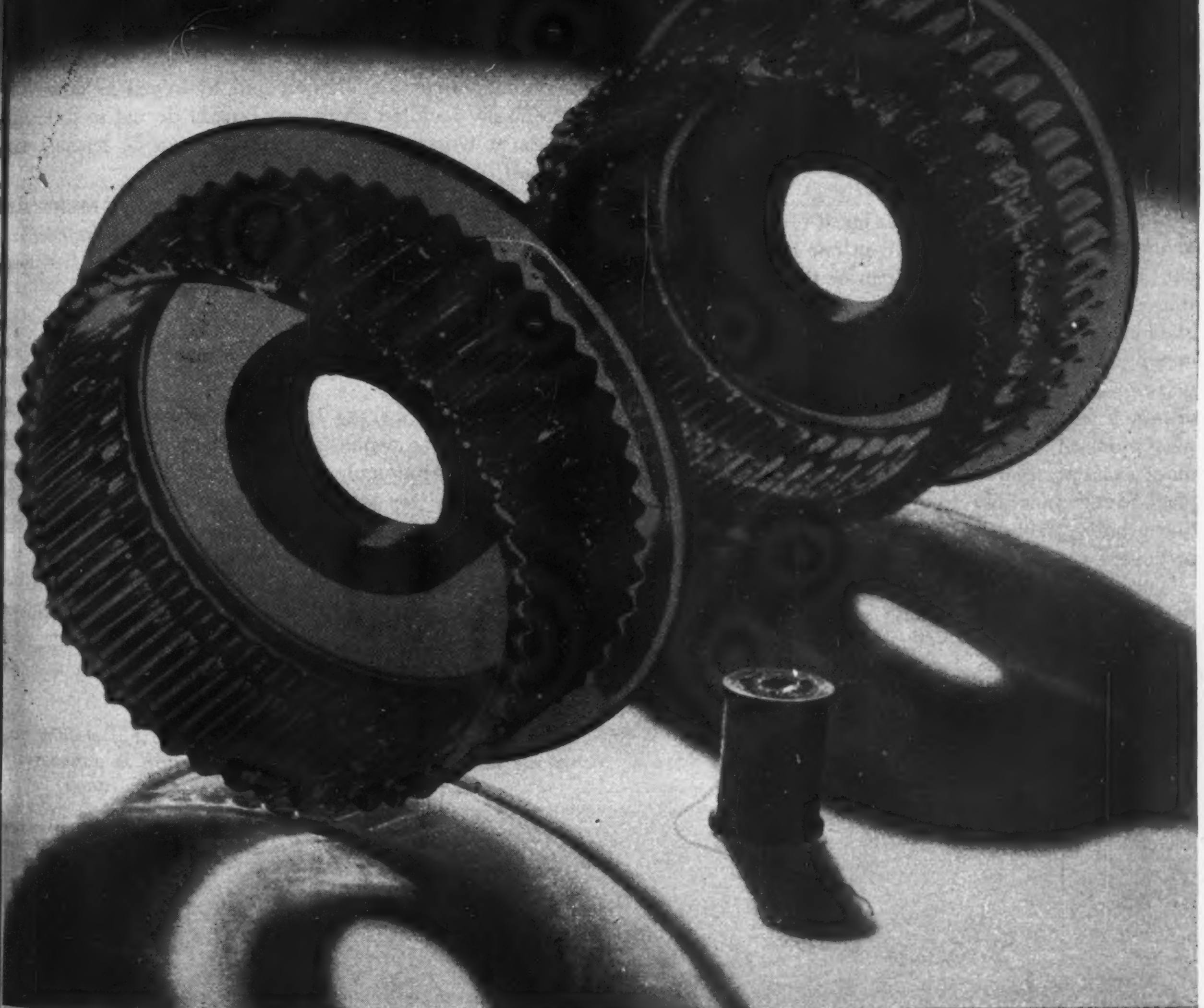


***Fig. 1** — Glass godet wheels for rayon spinning machines provide the necessary surface smoothness and high acid resistance*

ACCUSTOMED to using metals extensively and successfully, the machine designer may well wonder how glass can help him. It is not probable that glass will replace metals for use as a general construction material, but it can and does provide a solution to many specialized problems for which other materials are not suitable. The number of such applications is on the increase

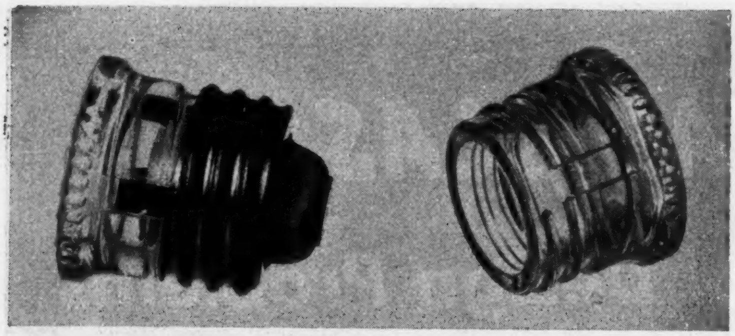


Fig. 2—This part is hot-pressed in one operation. Threads, keyways, serrated edges, etc. can be produced with little difficulty

due to improved techniques both in making glass and in fitting it to its intended purpose, and it is believed that many other uses will be found when the latent possibilities of this material are realized.

Before discussing a few specific cases, the characteristics of glass that make it a useful engineering material will be reviewed. Its transparency, corrosion resistance, smoothness and hardness are well recognized and it is not necessary to elaborate on them here. Some other properties, however, are also important but somewhat less known. These will be discussed in detail.

MOLDABILITY: When glass is hot it often can be molded to the required shape and size in one operation. If this is not possible the piece usually can be finished in one or two subsequent steps. Tolerances required in hot-molding glass are practically always greater than for corresponding metal parts made by die casting or machining. Molded glass parts may vary from plus or minus 1/64-inch to plus or minus 1/16-inch on dimensions across the mold, and somewhat more on dimensions along the axis of the mold. When more exacting tolerances must be maintained the molded glass blanks generally are ground. Grinding glass is much like grinding metal except that wheel loadings are lower and more care must be used in handling the work pieces.

Tubular shapes with precise bore dimensions can be formed by heating the blanks and pressing them onto a steel mandrel. Glass is released from the mandrel easily on cooling because the steel, having the higher coefficient of expansion, shrinks away from the glass. Bore dimensions can be held to plus or minus 0.0001-inch where necessary.

DIMENSIONAL STABILITY: Once molded, gro[und] or otherwise formed, glass does not change dimension. Neither age nor moisture nor appl[ied] working stresses will permanently distort it.

HEAT RESISTANCE: Borosilicate glasses used [for] ordinary industrial purposes will withstand tem[-] peratures well over 600 F. A new high-silica gla[ss] designed for high temperature service can b[e] used at 1650 F.

THERMAL SHOCK RESISTANCE: Borosilica[te] glasses having a low coefficient of expansi[on] usually will withstand plunging from boili[ng] water to ice water if sections are not over ½-inc[h] in thickness. High silica glass of the clear tran[s]parent type does not break even when plunged into i[ce] water while at glowing red heat.

CONTROLLABLE EXPANSION COEFFICIENT: Glasses a[re] available with thermal expansion coëfficients ranging, i[n] steps, from approximately the same as that of steel dow[n] to one-sixteenth the coefficient of steel.

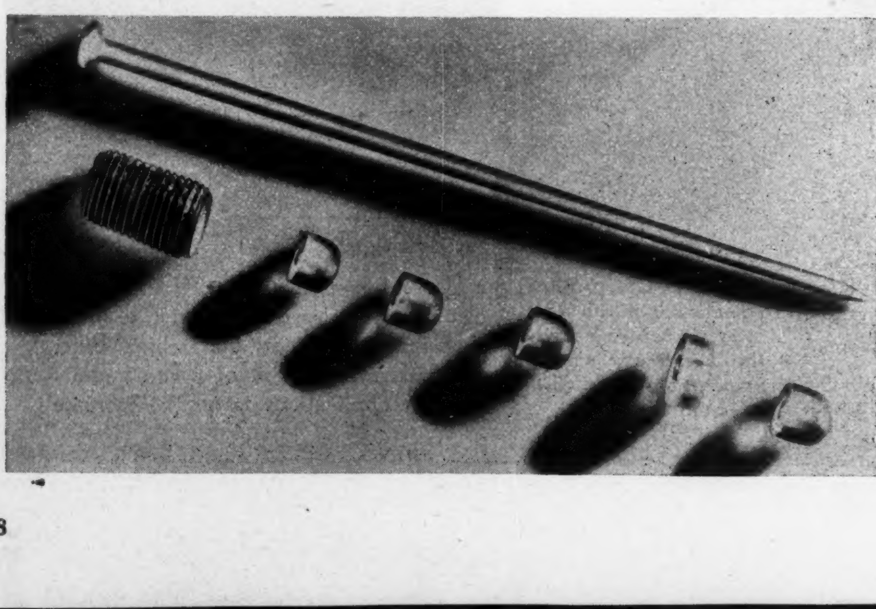
IMPERVIOUSNESS: Helium and hydrogen in addition [to] ordinarily handled gases and liquids do not seep thro[ugh] glass at working temperatures and can be securely con[-] tained.

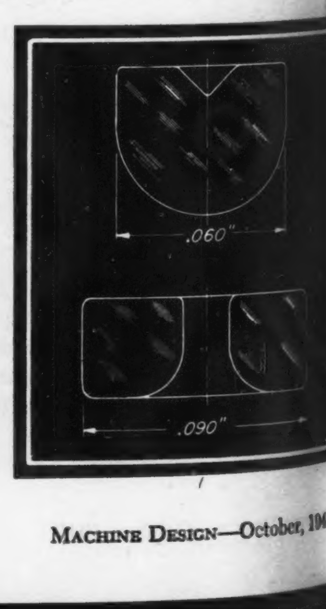
DIELECTRIC STRENGTH AND ELECTRICAL RESISTIVIT[Y]: Not subject to surface carbonization, glasses are excelle[nt] electric insulating materials in that they are free fro[m] "tracking" due to arcs or leakage currents.

Expansion Minimized

SEALING TO METAL: Hard borosilicate glasses for indus[-] trial use have expansion coefficients much lower tha[n] those of the commonly used metals and special technique[s] must be used for sealing them together. One method fre[-] quently used for sealing hard glass to metal involves th[e] use of Kovar, a specially prepared metal that has th[e] same expansion coefficient as one of the hard glasses. Gla[ss] and metal can thus be sealed directly together witho[ut] use of an intermediate bond. Another commonly use[d] method is to apply a strongly adherent metal coating [...]

Fig. 3—Below—Instrument bearings are hot molded fro[m] glass so accurately that finish grinding is unnecessary. Ordinary straight pin shows size range





surface of the glass and then soft- der the glass and metal parts together. esses due to difference in expansion fficients are minimized by making the tions of the metal component light ough to prevent overstressing the ss.

STRENGTH: From the point of view of machine designer the most impor- t limitation of glass is its low tensile ength. Maximum permissible working ess for ordinary tubing and molded rts is 1000 psi. Certain shapes permit npering and when this is possible, rking stresses can be increased to 3000 . Where ideal working conditions are countered stresses as high as 4000 psi have been used. Obviously enough, when glass is used for a machine t it is because one or more of its useful properties are quired. Following are some of the recent applications of h-strength glass which illustrate the principles govern- the proper application of glass as a useful engineering terial.

Fig. 4—Above—Glass with controlled expansion is used to hermetically seal leads into the cases of electrical instruments. Photo courtesy Marion Electrical Instrument Co.

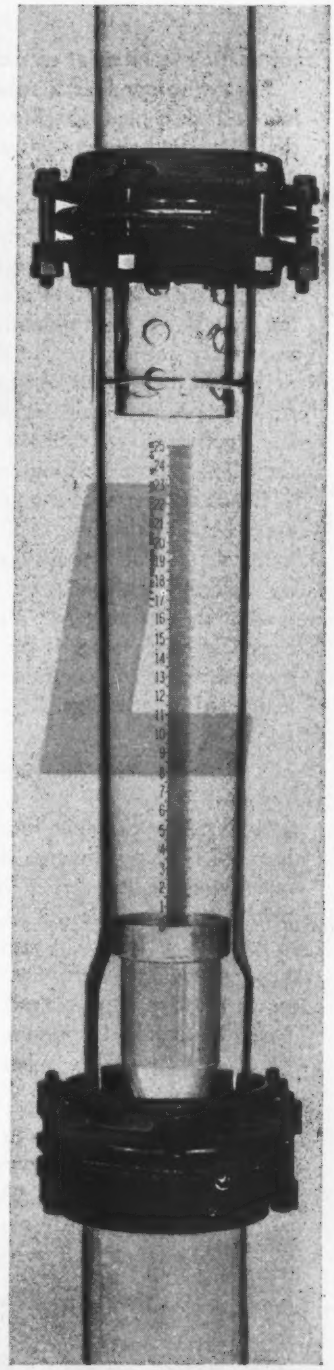


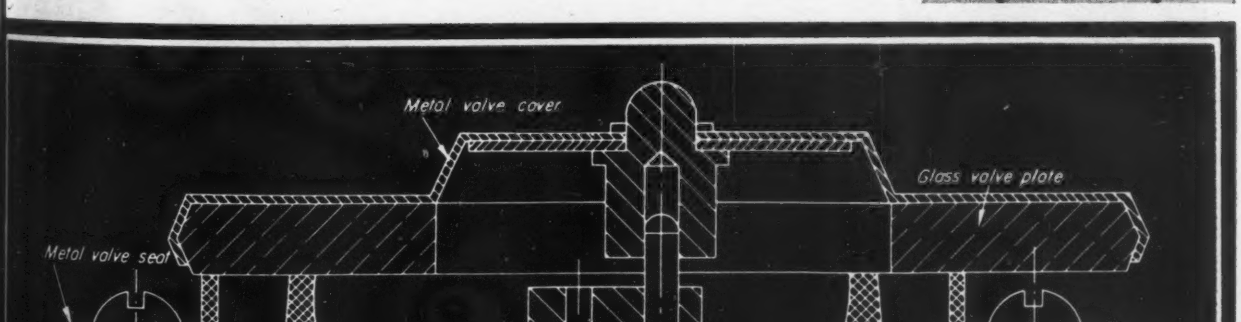
Fig. 5—Right—Long tubes can be produced easily with a taper bore accurate to plus or minus 0.0002-inch. Photo courtesy Fischer & Porter Co.

Useful Properties

A rayon spinning or godet wheel, *Fig.* 1, is a driven lley used on a rayon spinning machine that draws the n from an acid bath as it leaves the spinneret. A lead shing or hub is cast in place on the wheel to facilitate ing to a drive shaft. Corrosion resistance of glass is portant in this application as the yarn is wet with acid en it leaves the bath. In addition, "as molded" smooth- ss is another important property inasmuch as the slight- t roughness would injure the yarn. These wheels are olded to size in one low-cost operation and only two ishing steps are necessary—hole drilling and casting in a d hub. The running surface requires no polishing or ating.

Although the fuse plug shell *Fig.* 2, is not specifically a achine part, it is essentially similar to many machine rts and illustrates a combination of features that are of rticular interest to machine designers. These shells, com- ete with threads, wire groove and finger grips, can be olded to final dimensions in one operation on high-speed

Fig. 6—Below—Low-density hard glass is used to obtain smooth sliding action and good sealing in slide-plate gas meter valves. Photo courtesy Sprague Meter Co.



automatic machines at extremely low cost.

First developed as a substitute for jewel bearings, low-cost glass bearings, *Fig.* 3, have performed so well that they will undoubtedly continue to be used for many purposes. Made of a glass having exceptionally high bearing strength and surface hardness, glass bearings under shock conditions can be subjected to compressive stresses as high as 1,000,000 psi. Probably the most important advantage of glass as a bearing material is its moldability. Glass bearings can be accurately hot molded, no grinding or polishing being necessary. As a result, abrasive particles in the bearing recess resulting from grinding cannot cause wear of the steel pivot. In addition, steel pivots run freely on the glass without galling and with low friction drag.

Leads for hermetically sealed electrical instruments must be insulated where they enter the case and the joint must be absolutely tight. This problem is solved by sealing each lead into a glass bushing and then sealing the bushing into the instrument case, *Fig.* 4. Specially made glass is required which has the same thermal expansion coefficient as the metal used in the leads and case fittings.

Precision Bores Molded

Accurately tapered precision-bore glass tube is the heart of the variable-area flow meter, *Fig.* 5, used for measuring the flow rate of liquids and gases. Employed primarily for metering corrosive fluids, dimensional stability over years of service under wide ranges of temperature, pressure and exposure is of utmost importance. Such tubes must withstand high operating temperatures and sudden temperature changes. Tapered precision bore tubes are molded to exact size without grinding or polishing.

Glass slide valve disks for gas meter valves, *Fig.* 6, must move freely and seal tightly against a metal seat. Low-density hard borosilicate glass is used to obtain lightness and long wear. Dimensional stability enables such disks to resist warping due to age, moisture or temperature changes. Use of glass obviates corrosion and protects the die-cast metal seat from the galvanic action that might occur with metal disks.

Precision Grinding Utilized

An all-glass centrifugal acid pump has several parts that are particularly interesting to machine designers. The impeller, *Fig.* 7, has these features:

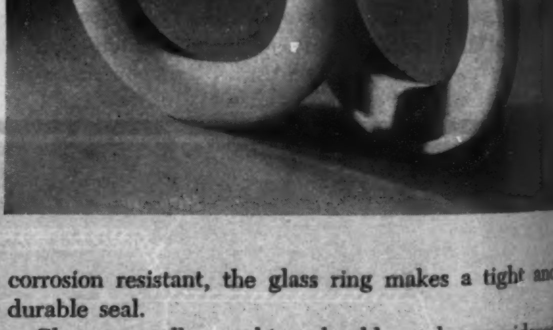
1. It is precision ground on virtually all surfaces
2. Stub shaft and impeller proper are molded in one piece
3. A steel quill or drive shaft is locked into the hollow stub with an alloy having a low melting temperature.

In the pump a seal ring *Fig.* 8, runs against a carbon ring to seal the impeller shaft entrance. Should the pump momentarily run dry, the glass seal ring is severely heated by friction. Made of thermal shock resistant high-silica glass, it is unaffected when liquid is again admitted. Being dimensionally stable and corrosion resistant, the glass ring makes a tight and durable seal.

Glass generally speaking should not be considered as an engineering material capable of replacing, even in a small measure, the metals and plastics that the machine designer uses today. Rather it should be looked upon as an auxiliary material. Used in the proper places, it can simplify the designer's task when he encounters problems requiring some of the properties found only in glass.

Fig. 7—Below—Capable of operating at speeds up to 3600 rpm, this pump impeller is unaffected by almost any corrosive fluid except hydrofluoric acid

Fig. 8—Below—Low expansion, high shock resistance and dimensional stability are outstanding characteristics of glass seal rings for corrosive applications



Selecting Materials for the Jeep

STARTING point for the selection of materials for vehicles such as the Jeep, shown above, must be the establishment of standards for performance, such as ermissible rates of wear and corrosion under normal conitions of service. These standards ust be revised periodically to take dvantage of improved materials and esign, and to meet the increasing emands of customers. In most veicles, failures due to actual breakge of parts have become relatively re. However, wear and corrosion emain to be eliminated, although heir severity is being reduced contantly.

Among the principal metal parts ubject to wear in automotive engines such as that of the Jeep, *Fig.* , may be mentioned the cylinder ore, piston, piston rings, bearings, and gear teeth. Corosion is encountered in the paint and electroplating aplied to exposed steel surfaces, and also in exhaust valve eads and distributor and spark plug points.

How much allowance should be made for abnormal conitions of service must also be decided at the outset of a ew design. For instance, decorative chromium plating that withstands several years of exposure in normal atmospheres may shown signs of pitting and rusting after a few months in humid, industrial, or salt-laden atmospheres. During the war, vehicles have been operated under conditions far different from those their designers originally anticipated — mud, tropical heat, arctic cold, fungi, and desert sand storms.

By Roger F. Mather

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Part I— General Considerations

Testing: After standards of performance have been established and tentative materials and designs selected, parts and assemblies must be tested before production is begun. Since vehicles are designed for many years of life, testing under average service conditions is usually infeasible. Therefore proving ground, dynamometer, and other simulated functional tests are established and correlated with service reports. In all kinds of laboratory and proving-ground tests, the types of failures produced must resemble those produced under service conditions. If a laboratory test shows failure of a steel part due to impact, a decrease in hardness is indicated; but, if the service results show a fatigue failure, an increase in hardness is more likely to be the remedy. After production of a new

vehicle has begun, service reports must be evaluated carefully and any necessary modifications made.

MATERIALS AND DESIGN: Most parts originally are designed with a definite type of material in mind. If preliminary tests show the part to have insufficient or excessive strength, then the material may be modified and the design left unchanged in order to take advantage of existing tooling. If the strength is insufficient and no better materials are available, entire redesign may be needed.

Some engineers have been prone to ascribe failures in experimental parts to the material specification rather than to the factors of design, processing, and assembly. As a result, more expensive materials have been substituted without good cause. One authority has stated that in his experience only one out of ten such failures could be traced to metallurgical factors of any kind. Nevertheless, both satisfactory and unsatisfactory parts usually should be examined after testing for conformance to material specifications. The use of magnaflux and similar methods for checking experimental parts before installation is recommended in some cases in order to detect surface and subsurface flaws, even when such inspection is not intended in production.

IN THIS FIRST ARTICLE of a two-part series, the author stresses general factors of importance in the selection of materials for all types of machines. Part II, to appear next month, will deal specifically with the factors involved in determining the materials best suited for various parts of the Jeep

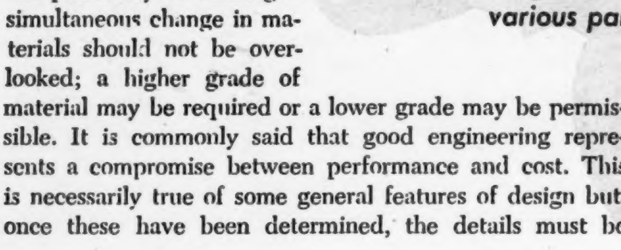
Materials and design are so closely related that when a change in design is made the possibility of making a simultaneous change in materials should not be overlooked; a higher grade of material may be required or a lower grade may be permissible. It is commonly said that good engineering represents a compromise between performance and cost. This is necessarily true of some general features of design but, once these have been determined, the details must be worked out so as to give satisfactory performance—without compromise.

MATERIAL SPECIFICATIONS: Specifications for materials go hand in hand with their selection. The primary purpose of the specifications is to facilitate inspection of the materials for conformance to the properties desired; the production parts must resemble within reasonably close limits the parts that were tested successfully. As far as possible, specifications should be confined to those properties that can be most readily inspected in the finished part. Specifications for the processes to which a part is subjected generally should be omitted because they are more difficult to enforce, particularly in suppliers' plants. For instance, the desired combination of strength and ductility on most hardened and tempered parts should be obtained by specifying the final hardness rather than the tempering temperature. Instructions to the heat treating department regarding details of processing should, for maximum flexibility, be issued as a separate sheet rather than put on the drawing itself. On the other hand, process specifications on the drawings are justified when no practicable means exist for checking the required properties in finished parts. For example, carburized gears are tempered at about 300 to 400 degrees Fahr. after hardening, chiefly in order to remove stresses caused by quenching. Measurements of these residual stresses would be impracticable to make in the form of a production operation. The hardness is decreased slightly by the tempering operation but the average as-tempered hardness is no less than the lowest as-quenched hardness. Therefore a hardness specification is unsuitable for detecting whether the tempering operation has been properly performed. As a result a process specification stating that the gears must be drawn at, say, 350 to 400 degrees Fahr. is justifiable in this instance. Process and inspection specifications should never be used simultaneously for the same property on the same part; only one is necessary and the two may conflict.

Specifications generally should cover only the minimum number of properties required to insure proper performance. However, in some instances the inclusion of properties not in themselves essential is justified for the purposes of inspection and production control. As an instance, tensile strength is not important in a part to be loaded in compression, but affords a suitable means of checking that the material is satisfactory. The same is true of elongation in the large number of applications where even a small amount of permanent extension would so interfere with adjacent parts as to ruin the assembly entirely. Hardness too is a property not often critical in itself because relatively few parts fail on account of low indentation resistance. The hardness test, however, is easily made and the results have been correlated with strength and wear resistance.

Another important function of specifications is to inform the supplier of the customer's needs. In certain instances, such as deep drawn parts, details concerning the material may be decided by the supplier, in which case he re-

Fig. 1—Cross section through Jeep engine reveals many parts requiring extreme care in materials selection



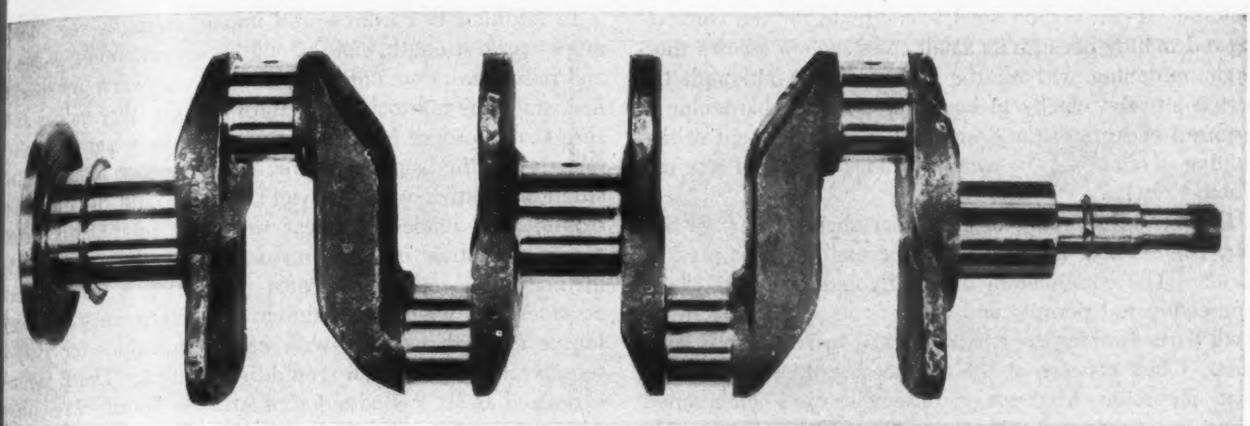


Fig. 2—Jeep crankshaft is forging of carbon steel AISI C-1040 which, although shallow hardend, suffices because part is stressed chiefly in torsion and bending

quires information regarding the fabrication and functioning of the part and assumes some responsibility in these respects. Another purpose of specifications is to help the purchasing department in developing optional sources of materials.

Until the beginning of the war, Willys-Overland used its own specifications for almost all productive materials except paints, which were purchased according to brand names. These specifications were relatively long and detailed, and were submitted to prospective suppliers as separate sheets. Since that time, the company has made a practice of using the most universal specifications available for each type of material, and this procedure has helped greatly to ease the problems of availability.

Generally speaking, the most satisfactory specifications are those in which both customers and suppliers have been consulted. This usually is the case in the specifications issued by the Society of Automotive Engineers, American Standards Association, and American Society for Testing Materials. Customers and suppliers are represented in equal numbers on the sections comprising the SAE-ASTM committee on automotive rubber, and their specifications have met with widespread acceptance.

In the absence of more generally recognized paint specifications, the company is now using its own standards in place of the brand names previously employed. For nonproductive coolants and lubricants, company specifications also replace brand names. The extent to which such specifications are used depends on the volume of the consumer's business, which must be sufficient to offset the cost of establishing the specifications, finding approved sources, and testing in production.

The remaining section of this article will deal with the principal types of parts used in the Jeep grouped according to form and type of material.

Plain Carbon Steel Forgings: Principal plain carbon steel forgings in the Jeep are the crankshaft, *Fig.* 2, and connecting rod, *Fig.* 3, which are made of AISI C-1040 and C-1141, respectively. Plain carbon steel is adequate for the crankshaft largely because it is amply designed to afford sufficient rigidity, so that stresses are relatively small. The steel is shallow hardening, but this is unimportant because the part is stressed chiefly in torsion and bending, resulting in low stresses at the center. It may be mentioned that some metallurgists believe that high strength at the center is desirable even when the part is stressed only in torsion and bending. A carbon content of 0.40 per cent is required to secure sufficient hardening on quenching, but a further increase would lead to more difficult machining and to lower ductility after tempering to the required hardness. Free machining steel, AISI C-1141, has been tried for the crankshaft, but the improvement in machinability did not justify the extra cost of the

Table I

Frequency Distribution Study of Physical Property Tests

(for establishing specifications for Jeep connecting rod)

Tensile Strength (psi)	Number of Tests	Yield Ratio* (%)	Number of Tests	P Factor**	Number of Tests	Charpy Impact (ft lbs)	Number of Tests
100,000	18	72	14	78	3	28	6
102,000	34	74	28	80	1	30	8
104,000	28	76	47	82	..	32	28
106,000	20	78	37	84	5	34	20
108,000	30	80	28	86	5	36	29
110,000	17	82	12	88	5	38	19
112,000	17	84	13	90	22	40	20
114,000	16	86	4	92	37	42	7
116,000	5	88	5	94	36	44	7
118,000	3	90	..	96	48	46	4
		92	1	98	24	48	1
				100	2	50	3
						52	1
						54	2
Total	188	Total	189	Total..........	188	Total.........	165

*Yield Ratio = Yield Strength/Tensile Strength.
**P = (6 × Reduction of Area + Tensile Strength/1000)/5.

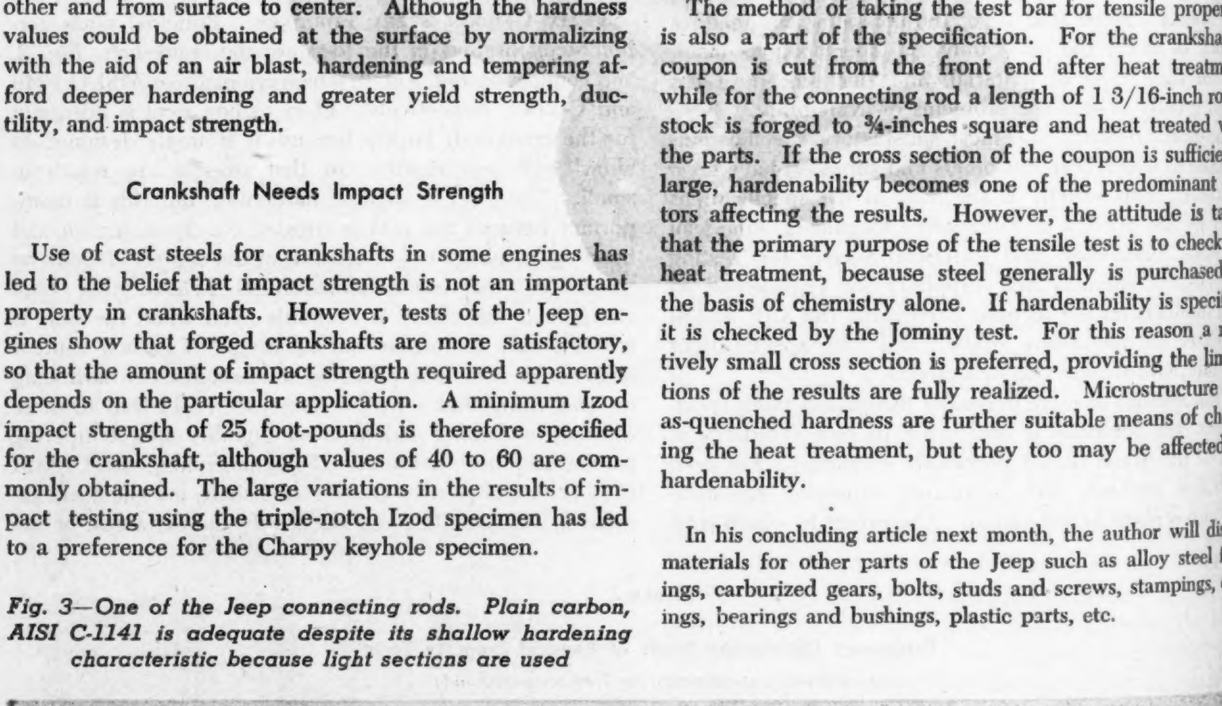
material. Plain carbon steel is adequate for the connecting rod mainly because its small cross section assures thorough hardening without the use of alloys; although the part is stressed chiefly in bending, thorough hardening is required because of the design. The large amount of machining in relation to its weight justifies the use of free machining steel.

In spite of its relatively irregular shape and high carbon content the crankshaft is successfully quenched in water. The combination of design and materials of the connecting rod permits and requires its quenching in oil. Both parts are tempered to about 210 to 260 brinell hardness. Chief concern of the engineering division is seeing that minimum hardness requirements are maintained, since the hardness is far from the brittle range. The machining department prefers the better machinability afforded by the low side of the hardness range. On the other hand, the heat treating department prefers the high side of the range, because pieces that are too hard need only be retempered, whereas pieces that are too soft must be both rehardened and retempered. The manufacturing division may balance these two factors as it sees fit and may accordingly aim at a restricted hardness range within the overall limits specified. Locations at which the hardness readings are taken are also stipulated, because the hardness varies considerably from one cross section to another and from surface to center. Although the hardness values could be obtained at the surface by normalizing with the aid of an air blast, hardening and tempering afford deeper hardening and greater yield strength, ductility, and impact strength.

Crankshaft Needs Impact Strength

Use of cast steels for crankshafts in some engines has led to the belief that impact strength is not an important property in crankshafts. However, tests of the Jeep engines show that forged crankshafts are more satisfactory, so that the amount of impact strength required apparently depends on the particular application. A minimum Izod impact strength of 25 foot-pounds is therefore specified for the crankshaft, although values of 40 to 60 are commonly obtained. The large variations in the results of impact testing using the triple-notch Izod specimen has led to a preference for the Charpy keyhole specimen.

Fig. 3—One of the Jeep connecting rods. Plain carbon, AISI C-1141 is adequate despite its shallow hardening characteristic because light sections are used

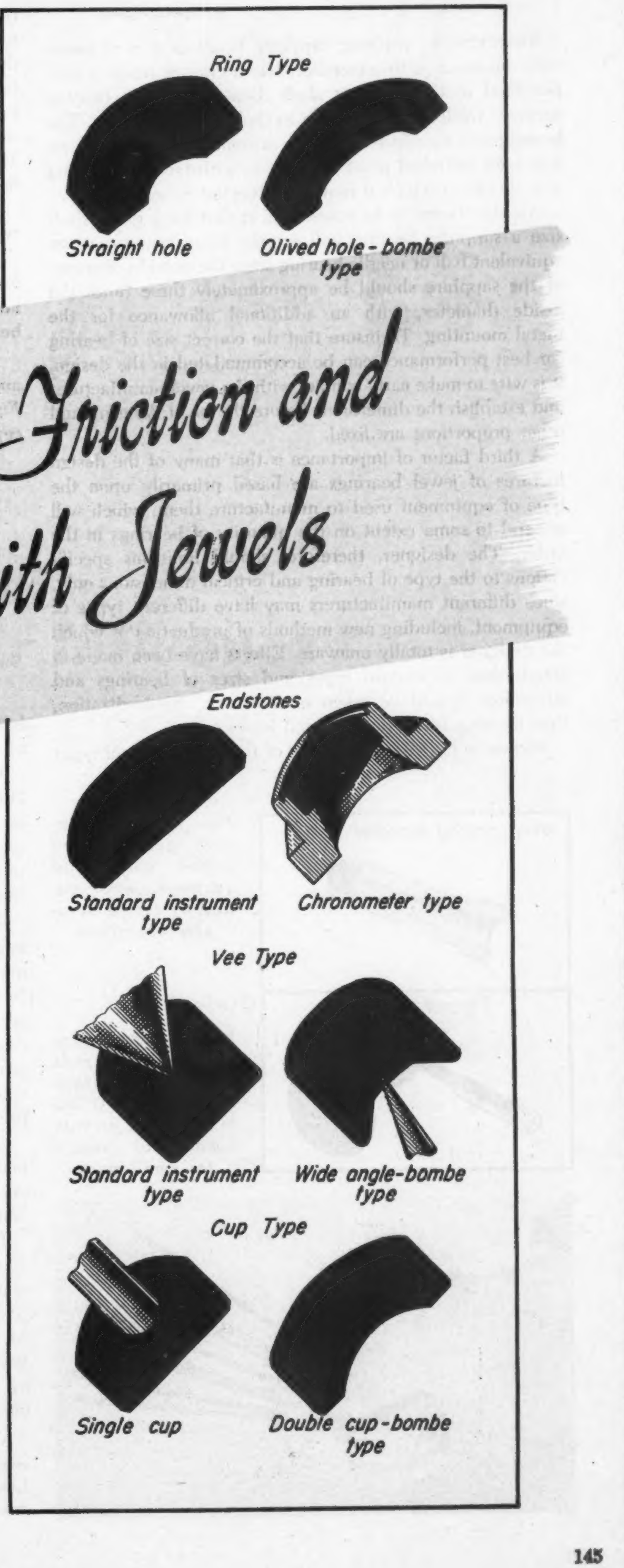


In addition to hardness and impact strength, the minimum tensile strength, yield strength, elongation in 2 inches, and reduction of area are specified. No maxima are specified, since the minima for strength and ductility values assure that a proper balance between the two factors is obtained. A disadvantage of this system is that high tensile strength together with low yield strength and ductility resulting from inadequate heat treatment might still meet the specification in some cases. Therefore a revised method of specifying physical properties is now under consideration whereby maximum and minimum values for tensile strength together with minimum values for yield-tensile ratio and P factor would be specified. The P factor is defined as (6 × Reduction of Area + Tensile Strength/1000)/5, and is more or less independent of the tempering temperature. Like the yield ratio, it is a good measure of the response of the steel to heat treatment. Values for these specifications are determined by frequency distribution curves on production parts. A listing drawn from such curves, applying to the Jeep connecting rod, is given in Table I. Random distribution curves always show a small percentage of maximum and minimum values. The specified ranges can therefore be made narrower by permitting one sample in each lot to fall outside the specified range providing that two additional samples meet the specification.

The method of taking the test bar for tensile properties is also a part of the specification. For the crankshaft a coupon is cut from the front end after heat treatment, while for the connecting rod a length of 1 3/16-inch round stock is forged to ¾-inches square and heat treated with the parts. If the cross section of the coupon is sufficiently large, hardenability becomes one of the predominant factors affecting the results. However, the attitude is taken that the primary purpose of the tensile test is to check the heat treatment, because steel generally is purchased on the basis of chemistry alone. If hardenability is specified, it is checked by the Jominy test. For this reason a relatively small cross section is preferred, providing the limitations of the results are fully realized. Microstructure and as-quenched hardness are further suitable means of checking the heat treatment, but they too may be affected by hardenability.

In his concluding article next month, the author will discuss materials for other parts of the Jeep such as alloy steel forgings, carburized gears, bolts, studs and screws, stampings, castings, bearings and bushings, plastic parts, etc.

Fig. 1—Typical examples of jewel bearings. Ring types take radial loads only, endstones are for thrust, while cup and V-types tal e combination loads. V-type is the most generally applicable for light loads



Reducing Friction and Wear with Jewels

ALTHOUGH sapphires and rubies have been used for many years as bearings in watches, clocks, electrical instruments, compasses, etc., recent demands for exceptionally hard materials have opened up many new fields of application. Possessing unique characteristics which fit them preeminently for certain special jobs, these materials have potential uses as yet unexplored. It is the purpose of this article to present basic information which will guide designers in evaluating the suitability of sapphires for applications in their own designs.

Consisting of crystalline aluminum oxide Al_2O_3 (corundum), sapphire is available in both natural and synthetic forms. The physical characteristics, Table I, of the two varieties are so nearly identical that they are equally satisfactory for almost all industrial purposes. Limitations on their use are controlled primarily by size requirements, availability and manufacturing requirements. Surprisingly enough, the cost is not as high as the price of gem stones at the local jeweler's would lead one to expect and has been justified repeatedly by the unusual performance and durability in applications involving friction.

From the viewpoint of the machine designer, the major applications may be classified under the following general heads:

1. Bearings
2. Guides
3. Orifices
4. Special parts

Bearings: In applying sapphire bearings it is of particular importance to remember that friction is roughly proportional to the pivot or shaft diameter on the bearing surface, while cost increases as hole size increases. The bearing size therefore should be as small as possible consistent with sufficient pivot strength to withstand the loading and shocks to which it may be subjected in service .

Another factor to be considered is that for a given shaft size a sapphire bearing will require more space than an equivalent ball or needle bearing since the outside diameter of the sapphire should be approximately three times the inside diameter, with an additional allowance for the metal mounting. To insure that the correct size of bearing for best performance can be accommodated in the design, it is wise to make early contact with the jewel manufacturer and establish the dimensions before the pivot, housing and other proportions are fixed.

A third factor of importance is that many of the design features of jewel bearings are based primarily upon the type of equipment used to manufacture them, which will depend to some extent on the quantity of bearings in the order. The designer, therefore, should limit his specifications to the type of bearing and critical dimensions only, since different manufacturers may have different types of equipment, including new methods of production of which the designer is totally unaware. Efforts have been made to standardize on certain types and sizes of bearings and advantage should be taken of any such standardization, thus insuring faster delivery and lower cost.

Shown in *Fig.* 1 are examples of the four principal types of jewel bearings. For relatively heavy radial loads ring type with straight hole is best suited. Hole sizes ca[n be] made as small as 0.003-in. and as large as ⅛-in. For [re]duced friction, an "olived" hole may be used. With [sur]face polished—either flat or "bombe"—light thrust may [be] taken care of. For heavier thrust or vertical mounting, [the] ring jewel should be used in conjunction with an endsto[ne]. Maximum practical dimensions of endstones are abo[ut] ⅜-in. diameter and 0.01-in. thickness.

Most adaptable for light general applications is the [V] type bearing, which is designed to take both radial [and] thrust loads with minimum friction. The cup type, design[ed] for vertical mounting only, supports thrust and li[mits] lateral movement to some extent, depending on the relatio[n] between pivot radius and bearing radius of curvature.

Guides: Mandrel guides for tungsten filament coil[ing] and thread guides for rayon or nylon fiber applicatio[ns], *Fig.* 2, are typical examples of the use of sapphire for ex[-] ceptionally severe wearing conditions. Mandrel guides ca[n]

Table I

Properties of Synthetic Sapphire

Density lb per cu in.	0.14[illegible]
Hardness (Moh's scale, diamond = 10)	9
Elastic modulus, psi	50-56 x 10[illegible]
Compressive strength, psi.	[illegible]
Tensile strength approx., psi	65,[illegible]
Specific heat at 25C	0.18
Thermal conductivity, cal/sec/cm/°C at 120C	0.0[illegible]
Thermal expanshion coefficient, per °C at 50C	
Parallel to C-axis	6.7 x 10[illegible]
Perpendicular to C-axis	5.0 x 10[illegible]
Melting point, deg C	[illegible]

be made with holes 0.002 to 0.030-in. with tolerance pl[us] or minus 0.00005-in.

Orifices: Similar to ring bearings and guides, sapphi[re] fluid orifices of great accuracy and dimensional stability ca[n] be made for air and gas measurement, oil burners, die[sel] injectors, etc. Because the material resists wear and corro[-] sion and retains its high polish, the metering characteris[-] tics are not subject to change.

Special Parts: Guide blocks, pins, wear plates, balanc[e] knife edges and other special parts of sapphire offer [a] means of meeting particularly severe local wear problems. In addition, plug and ring gages for extremely accurate in[-] spection work are finding increased application. Dies fo[r] drawing and extruding soft metals and plastics, als[o] grinding and burnishing wheels where maintenance o[f] wheel shape is vital, are among the uses of sapphire o[f] particular interest in connection with production.

Synthetic sapphire rod, *Fig.* 3, has greatly simplified the manufacture of small bearings and guides, which can be cut off as desired. The rod also may be bent, flame-shaped and flame-polished.

Because of the highly specialized techniques of jewel manufacture, the designer should work closely with the manufacturer and in all cases give him as free a hand as possible in the proportioning and design of sapphire parts. At the same time, to recommend suitable proportions the jewel manufacturer needs a full knowledge of every fac[-] tor such as speeds, loads, vibration, shock, and temperature variations, concerning the moving parts involved.

Machine Design acknowledges with appreciation the helpful cooperation of Aurele M. Gatti Inc. (*Figs.* 1 and 2) and The Linde Air Products Co. (*Fig.* 3) in the preparation of this article.

Fig. 2—Left—Mandrel guides and thread guides of sapphire resist unusually severe abrasive conditions

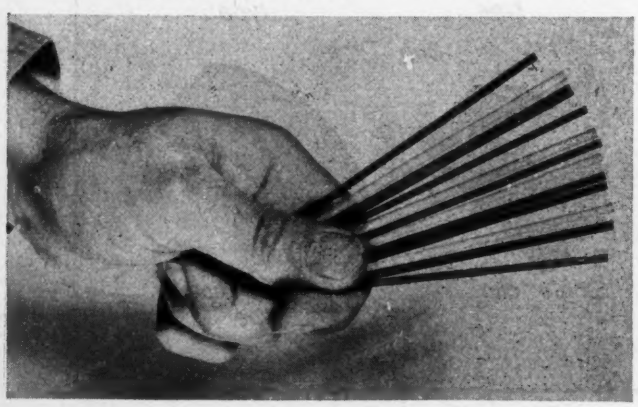
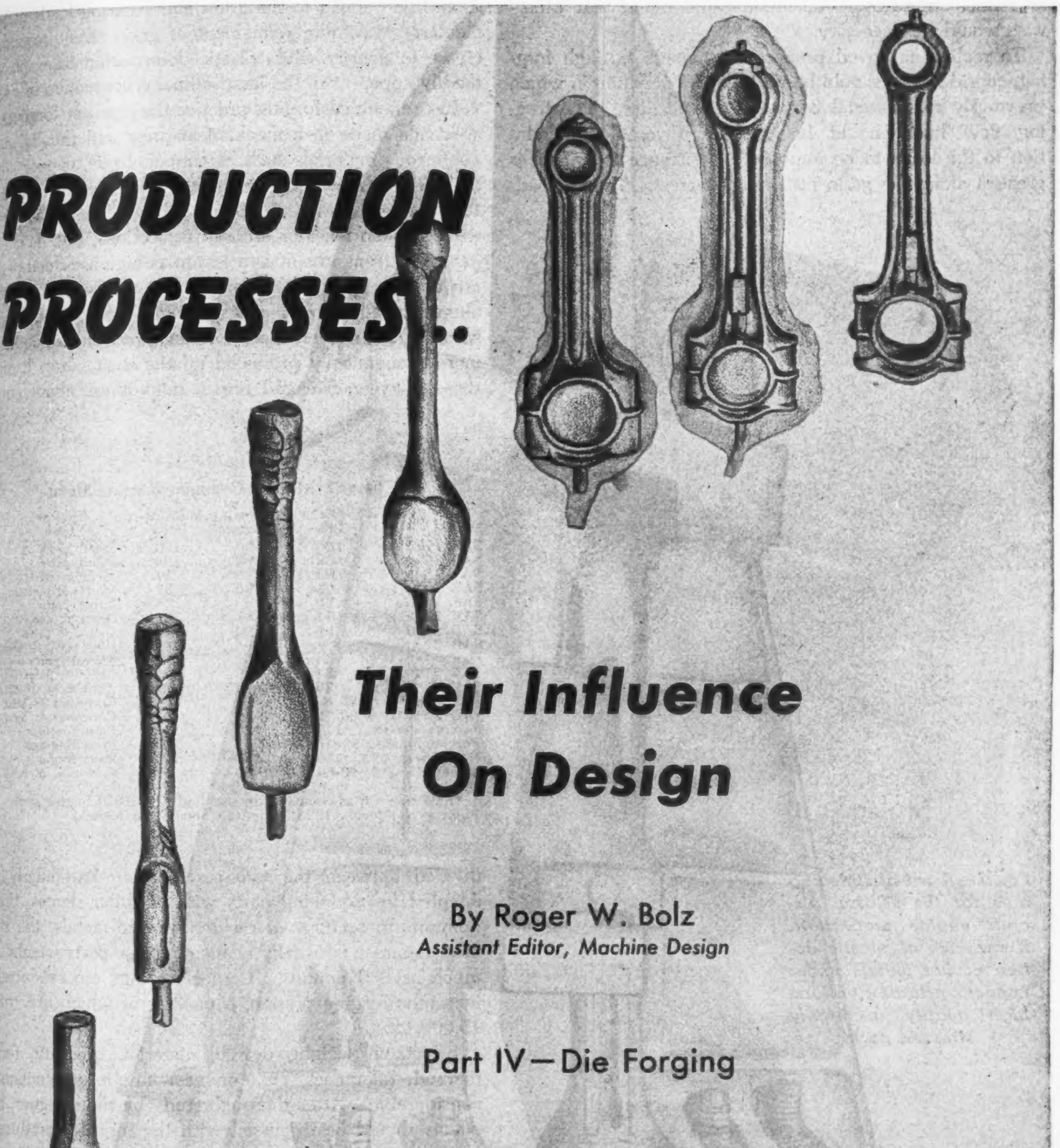


Fig. 3—Below—Synthetic sapphire rods having diameters ranging from 0.065 to 0.125-in. provide economical source for small parts

PRODUCTION PROCESSES...



Their Influence On Design

By Roger W. Bolz
Assistant Editor, Machine Design

Part IV—Die Forging

PRODUCTION by impact or pressure forging in closed impression dies merits top consideration in the design and specification of machine parts which must withstand unduly heavy or unpredictable loads. Although a few other production methods such as centrifugal and permanent-mold casting produce in occasional cases comparable results, the uniform high quality and overall dependability of properly designed die-forged parts are recognized readily. Such parts manufactured from a great variety of metals embrace an unusually wide range of machine applications including cams, levers, gears, connecting rods, crankshafts, pistons, axle shafts, propeller hubs, and a multitude of other units which must resist high stress or be pressure tight.

Accurate control of the forged metal in the two cavities of a set of dies, *Fig.* 1, is afforded mainly by good die design and a thorough understanding of the plastic action of various hot metals under impact or pressure. Knowledge of the basic principles of forging design, therefore, will enable the designer to utilize to the fullest those features which contribute to economy in production, affording maximum strength with minimum weight, high fatigue resistance, excellent surface finish and accuracy which eliminate

or reduce appreciably machining operations that otherwise would be necessary.

To realize improved properties available through forging, consideration should be given to the direction in which previously rolled metal is worked in the dies. The forging flow lines should be oriented favorably in relation to the loads to be imposed. Resistance to impact is greatest along the grain rather than across. Tensile loads should be parallel to the grain and shearing loads perpendicular. Maximum refinement of grain structure and increase in density while plastic deformation takes place is readily apparent in the longitudinal cross section in Fig.

In commercial forging practice the smallest forgings are as a rule made in a mechanical press and usually are of nonferrous materials such as copper, brass, copper alloys, etc. These may range from a few ounces to as high as thirty pounds, *Fig.* 3. Simple, relatively uniform parts without deep holes or difficult projections, *Fig.* 4, ranging in weight from an ounce or less to as high as fifteen pounds are usually forged from low carbon steels, copper alloys, aluminum alloys, or magnesium alloys on the board drop hammer. However, those ranging over fifteen pounds are more economically produced on the steam drop hammer; those between five and fifteen pounds are about equally

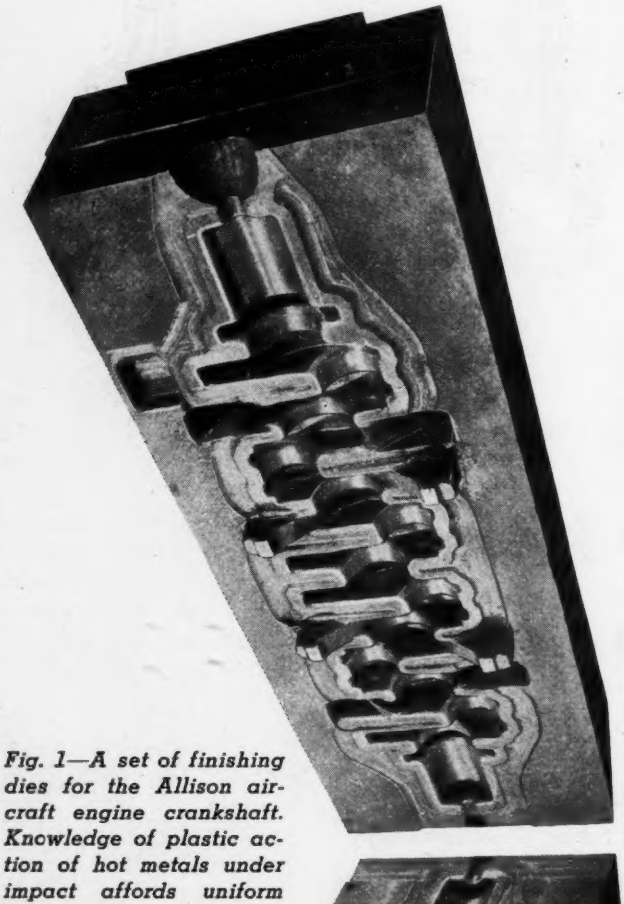


Fig. 1—A set of finishing dies for the Allison aircraft engine crankshaft. Knowledge of plastic action of hot metals under impact affords uniform high quality in highly stressed parts

Table I

Characteristics of Common Forging Metals*

Metal	Die Life	Production	Machinability	Typical Uses
SAE 1020	100	100	100	Small parts
SAE 1030	98	98	104	Small parts
SAE 1035	95	96	87	Medium parts
SAE 1040	95	96	81	Small & medium parts
SAE 1045	90	93	78	Large parts
SAE 2340	84	89	82	Gears & axles
SAE 3140	85	90	74	Gears & axles
SAE 3250	77	84	69	High strength parts
SAE 4140	84	90	83	Aircraft parts
SAE 5140	84	89	76	Gears & axles
SAE 6150	78	84	67	Antifatigue forgings
SAE 30915	20-65	80	50	Corrosion & heat
SAE X51410	30-70	85	80	Corrosion & heat
Forging copper	110	125	125	Press forgings
Forging brass	115	107	200	Press forgings
Naval brass	110	103	160	Press forgings
Monel	20-60	30-60	59	Corrosion & heat

*Ratios shown as compared to standard SAE 1020 forging steel. Fr *Forging Handbook*, 1943, American Society for Metals.

divided between the two machines. Particularly well adapted to producing parts with irregular shapes, thin or nonuniform sections in the less plastic metals, the steam drop hammer is usually economical for parts weighing as much as 300 pounds. Larger forgings are produced on hydraulic forging presses, capacities of which may run to 15,000 tons.

Effects of weight, design, material, quantity, forging method, tolerances, etc., on economy in production are considerable. After thorough study by the designer, these effects should be discussed with the forgings producer to arrive at a satisfactory compromise between optimum design and inherent limitations of the process.

Quantity runs are of course the most economical, die and set-up costs per piece being the lowest. Where quantities run at one time are small, say 200 to 400 pieces, die and set-up costs always assume a substantial portion of the total cost per piece. However, and most important of all, die life is affected directly by the number of times dies are refitted to the machine for producing a small lot. Thus the overall life of a die (in continuous production) may be reduced as much as 90 per cent by short run production in small lots of 100 pieces or less. Consequently, parts such as those shown in *Fig.* 5 and odd shaped complicated crankshafts can be produced more economically on flat-die steam hammers when quantities are extremely small or spread over a long period of time. Even though more machining usually is required for flat die work, this is justified by the saving in die costs.

All drop and press forgings usually require a trimming [e]ration to remove the excess metal or flash after leaving [th]e finishing impression of the die (see sequence of steps [in] forging a connecting rod, Page 147). Other finishing [ste]ps often required before completion include punching, [for]ming, straightening, broaching, coining or sizing, plan[ish]ing, and ironing. Trimming and punching operations [ar]e done either hot or cold. Small to medium size forg[ing]s ordinarily can be sheared or punched cold in low alloy [or] carbon steels up to 0.35 carbon. Large work and es[pe]cially high alloy parts are trimmed hot. The clearance [fo]r trimming usually runs 0.010-inch or a little greater de[pe]nding upon the flash thickness.

The various other operations are primarily intended for [fur]ther reducing machining work and in many cases can [eli]minate machining altogether. "Broaching" as termed [ab]ove is used as a multiple hot punching operation to re[mo]ve draft from a part of a forging, the tool having only [tw]o or three teeth. Forming is used extensively to pro[du]ce a special shape on part of a forging not ordinarily [po]ssible in the dies. This usually consists of bending, [tw]isting or drawing. Cold sizing or coining is used pri[ma]rily to attain closer dimensional tolerances than is pos[sib]le in the ordinary forging operation on relatively small [ar]eas. Hot sizing is used on large areas to achieve a con[si]derably improved surface and attain close control of di[m]ensions, alignment, and weight for larger parts. Iron[in]g, performed hot or cold, is used to improve surface

TABLE II

Forging Thickness Tolerances (inches)

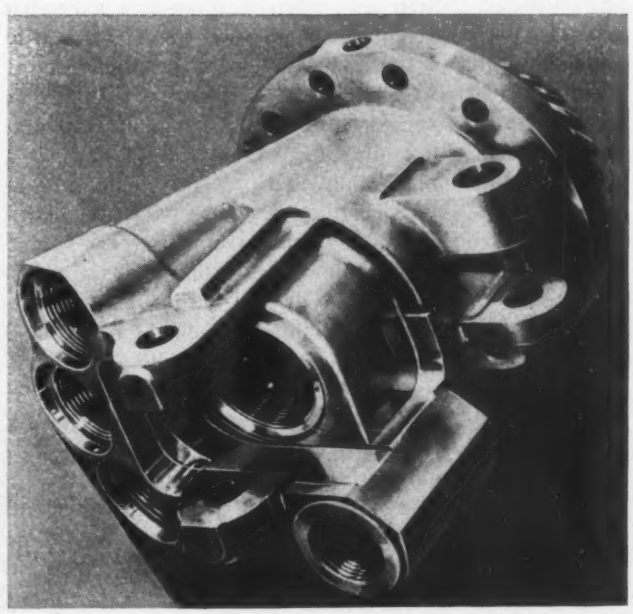
Net Weight (max lbs)	Commercial plus	Commercial minus	Close plus	Close minus
0.2	0.008	0.024	0.004	0.012
0.4	0.009	0.027	0.005	0.015
0.6	0.010	0.030	0.005	0.015
0.8	0.011	0.033	0.006	0.018
1	0.012	0.036	0.006	0.018
2	0.015	0.045	0.008	0.024
3	0.017	0.051	0.009	0.027
4	0.018	0.034	0.009	0.027
5	0.019	0.057	0.010	0.030
10	0.022	0.066	0.011	0.033
20	0.026	0.078	0.013	0.039
30	0.030	0.090	0.015	0.045
40	0.034	0.102	0.017	0.051
50	0.038	0.114	0.019	0.057
60	0.042	0.126	0.021	0.063
70	0.046	0.138	0.023	0.069
80	0.050	0.150	0.025	0.075
90	0.054	0.162	0.027	0.081
100	0.058	0.174	0.029	0.087

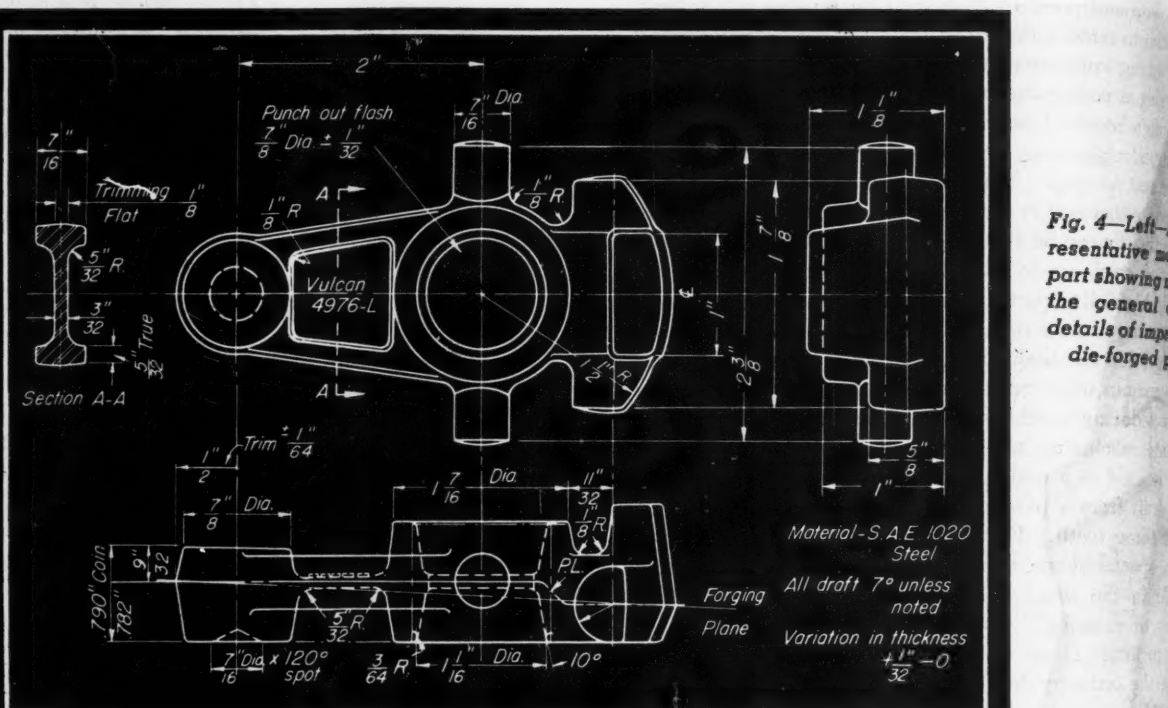
[fi]nish, remove draft from certain portions of a forging or [im]press markings. Planishing, a combination of ironing [an]d sizing, is used on rounded or spherical sections.

DESIGN: Primary among the design factors to be con[si]dered is the draft or draft angle, *Fig.* 4, required for easy [re]moval of the part from the die. Draft angles on por[ti]ons to be machined should be as small as possible, *Fig.* 6, [b]ut commensurate with increased die wear normally pres[en]t with the smaller angles. The normal draft angle for [ex]ternal surfaces of parts designed for the board drop [ha]mmer is 7 degrees and for internal surfaces, 10 degrees. Normal external draft angle for the steam drop hammer [i]s 5½ degrees and internal, 7 degrees. These can be varied [a]ccording to the design and may run from 1 degree on [s]hallow work to as much as 15 degrees on deep steel forg[in]g impressions. Questions arising on special jobs should

Fig. 2—Below—Macro-etch through a longitudinal cross section of an Allison crankshaft. Flow of metal and refinement of grain structure are readily apparent

Fig. 3—Below—Indicative of the extremely intricate design possible in hot-pressing nonferrous metals, this forging in the rough weighs approximately twelve pounds





be taken up with the forgings producer. Standard draft angles for forgings of nonferrous metals to be made in presses range from 2 to 3 degrees on all surfaces normal to the parting line. Spherical, cylindrical, conical, and like surfaces often can be included so as to provide natural draft, *Fig.* 4. Ends of cylindrical or conical parts have draft provided at the flat ends either as a flat cone or a spherical surface. Radial draft is usually assumed to be approximately twice the diameter of the projection but is seldom marked on drawings. Where draft must be otherwise it should be plainly marked.

In laying out a part and establishing a parting line, *Fig.* 4, good practice is to have approximately equal volumes both above and below. Where a straight parting line is not possible, *Fig.* 7, an irregular one, *Fig.* 4, usually can be established though more often than not at a somewhat increased die cost. Particular attention should be paid to utilizing natural parting planes wherever possible.

Corner radii and fillets should always be specified as large as possible to assist the flow of hot metal and promote economical manufacture. Long sweeps and large radii promote sound forgings and prevent defects such as coldshuts, laps, poor structure, etc. The minimum radius or fillet used runs from 3/64-inch on small parts to ⅛-inch on parts weighing 100 pounds. All dimensions are normally made tangent to corner or fillet radii, *Fig.* 4.

Abrupt changes in section thickness should be avoided inasmuch as the thin portions cool too rapidly and tend to set up severe stresses at the junctions. Web or rib sections less than 3/32-inch in thickness should be avoided, especially in alloy steels. Webs parallel to the parting line are difficult to produce in medium or large areas and a thickness over ⅛-inch is preferable for economy on all except certain small nonferrous hot pressings. In addition to maximum rib widths it is also desirable to keep rib heights as low as design will permit and attendant draft angles large as practicable. Corner radii on rib sections should be constant with variations taken by draft, *Fig.*

Where pockets and recesses are necessary, it is generally advantageous to make all connecting sweeps and draft angles as generous as possible. Needless to say such designs should be made no deeper than necessary to avoid undue die wear. Depth of a depression or forged hole should never exceed two-thirds of the narrowest portion.

Projection of bosses (length of projection less than diameter) extending vertically into the die cavity should

TABLE III

Shrinkage and Die Wear Tolerances
(inches)

Shrinkage			Die Wear		
Length or Width	Commercial (+ or —)	Close (+ or —)	Net Wt. (lbs)	Commercial (+ or —)	Close (+ or —)
1	0.003	0.002	1	0.032	0.016
2	0.006	0.004	3	[illegible]	0.018
3	0.009	0.005	5	0.038	0.019
4	0.012	0.006	7	0.041	0.021
5	0.015	0.008	9	0.044	0.022
6	0.018	0.009	11	0.047	0.024
For each additional inch add:	0.003	0.0015	For each additional 2 pounds add:	0.003	0.0015

held to a minimum wherever possible and in any case should never exceed two-thirds of the smallest diameter of the boss. However, those that lie parallel to the parting line may be considerably longer. Such projections are usually known as stems.

Where holes of ½-inch diameter or over are to be drilled, accurately placed drill spots of 105 to 120 degrees (included angle) can be provided on any surface approximately parallel to the forging plane, *Fig.* 4. These not only aid in drilling but also help considerably to refine the grain structure. If tolerances on hole location are not exacting, spots can be placed on both sides of the piece.

Locating points for machine operations should always be positioned away from the parting line. Die wear at the

line results in a continuously changing surface width ing it unsuitable for accurate locating.

aterial allowed for machining operations will vary ewhat with the size and shape of the part and with the of machining operation. Sufficient metal should be ided so as to allow easy positioning but in any case hining economy dictates a minimum possible amount. ll and medium sized parts with simple finishing op-ions usually have an allowance of 1/32-inch to 1/16- for machining. Larger parts may have allowances of ½-inch on machined surfaces depending upon the de- and intricacy. In most designs, even on small forg-, it is usually advisable to allow 1/16-inch for finish- if possible to assure machining beneath the scale pits other irregularities. Accurate parts such as crank-fts should have an allowance of ⅛-inch on the bearing aces. Forgings made with flat dies require a greater wance and small parts up to about 8 inches in diam-

Table IV

Die Mismatching Tolerances
(inches)

Net weight (max lbs)	Commercial	Close
1	0.015	0.010
7	0.018	0.012
13	0.021	0.014
19	0.024	0.016
For each additional 6 pounds add:	0.003	0.002

r should have an allowance of ⅛-inch for machining or nch on diameter. This allowance for machining is in-ased to ¼ or ½-inch on diameter for parts as large as inches in outside diameter. In most cases draft is con-ered as additional to the ordinary machining allowances. aximum allowable flash thickness should be specified most cases, especially where excess flash will interfere h machining or locating. Thickness should never be than 1/32-inch nor greater than ¼-inch.

aised lettering, trade marks, part numbers, etc., can furnished on any forging at little expense. These usual-are made as an insert in the die and should be so placed the part as to allow adequate area for such an insert d at the same time avoid subsequently machined sur-es. Marked surfaces must be on an area which lies proximately parallel to the forging plane.

aximum economy in production naturally is achieved reducing design to the simplest possible shapes and ms consistent with functional requirements. Straight angular parting lines are far more economical than ved ones. Intricate or nonuniform shapes parallel to parting line are often difficult to produce. Easiest to k in a die and least expensive to maintain is the circular ss section. Elliptical cross sections are equally eco-nical to reproduce. Parts to be forged in great num-rs often can be designed for multiple-cavity dies reduc-cost per piece considerably.

eduction in the number of machining operations nec-ary often can be achieved by utilizing the coining, form-, bending, twisting, broaching, drawing, ironing, plan-ng, and sizing operations available in the forge shop.

Materials: Of the common forging materials, SAE 20 usually is taken as standard and all other materials ged therefrom. As the carbon and alloy content of els increases, forging becomes more difficult and additional working operations are necessary. Most of the non-ferrous metals such as copper, forging brass, naval brass, bronze, and copper alloys are easily forged. Action of these metals combines extruding and forging making possible complicated pressings in one operation.

Table V

Draft Angle Tolerances
(degrees)

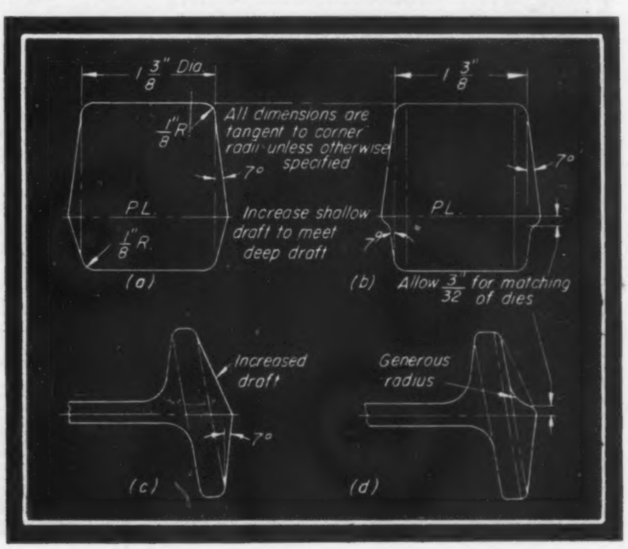
Type	Commercial	Close
Outside	0 to 10	0 to 8
Inside	0 to 13	0 to 8

Materials specified are as a rule selected on a compromise basis. First, the required strength and physical properties must be met. Corrosion resistance, size, toughness, fatigue resistance, heat resistance, and section thicknesses must be balanced properly against forgeability and machinability to achieve maximum economy. Table I outlines some of these factors with the comparisons based on SAE 1020 steel.

Tolerances: Maximum permissible tolerances should be indicated wherever possible. Forging dies are machined to the low limits specified for a part and when the impression has worn to the high limits the die must be

Fig. 5—Above—A group of representative flat-die forgings. Such parts are often forged in high-speed steels

Fig. 6—Below—Proper draft on portions to be machined, (b,d), often result in greater economy than tho seat (a,b)



scrapped or resunk. It follows without question that wide tolerances extend the die life considerably, especially with the tougher alloy steels.

The important tolerances to be considered by the designer as set forth by the Drop Forging Association are: (1) Thickness, (2) width and length as composed of shrinkage and die wear, mismatching and trimmed size tolerances, and (3) draft angle. These are of two classes —regular or special. Special tolerances cover those so indicated on each dimension and where no tolerances are indicated the regular usually apply. Regular tolerances as set up may be either "commercial" for general forging practice or "close" where extra care and accuracy sired at, of course, a somewhat increased cost.

Thickness tolerances, Table II, apply to the thickness perpendicular to the parting line of the Width and length tolerances apply to the portions in one die and lie in a plane parallel to the parting the dies. Similarly applying to dimensions which cross the parting line, shrinkage and die wear, Table are used as a unit rather than separately and do clude draft. Mismatching or displacement of one die the other, Table IV, is often a factor to consider curate work and may have detrimental effects if looked. Trimmed size of forgings is usually within sum of the limiting sizes imposed by draft angle, shrink and die wear variations. Draft angle tolerances are in Table V.

If tolerances closer than those ordinarily obtained required between two flat surfaces parallel to the parting line, coining or sizing may be specified. A tolerance plus or minus 0.005-inch can be held and on some as little as plus or minus 0.002-inch. Accuracy or proved finish can be obtained also on small parts having other than flat surfaces by cold coining. Similarly, restriking may be utilized on larger parts to obtain tolerances on weight as well as dimensions.

Collaboration of the following organizations in the preparation of this article is acknowledged with much appreciation: American Brass Co. (*Fig.* 3); Aluminum Company of America (*Figs.* 6, 7 and 8); Chambersburg Engineering Co.; Drop Forging Association (*Figs.* 1 and 2); Heppenstall Co.; Steel Armstrong Forge Inc. (*Fig.* 4); The Steel Improvement Forge Co.; J. H. Williams & Co. (*Fig.* 5); Wyman-Gordon

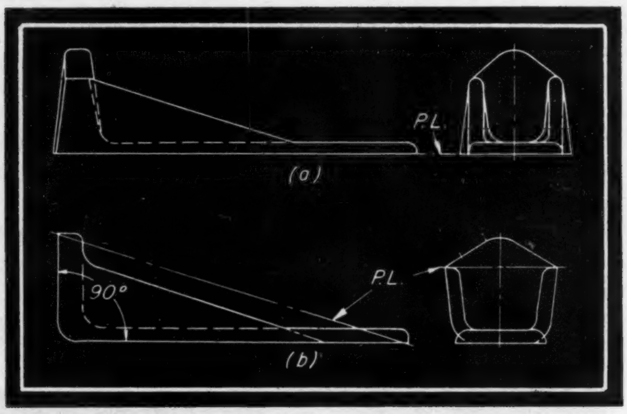


Fig. 7—Above—Designs can be altered slightly to provide various ways for parting. Considering die cost, a is most economical but* b *provides a lighter part without end draft

Fig. 8—Below—Rib designs should provide for constant edge radii in female die portions to simplify sinking

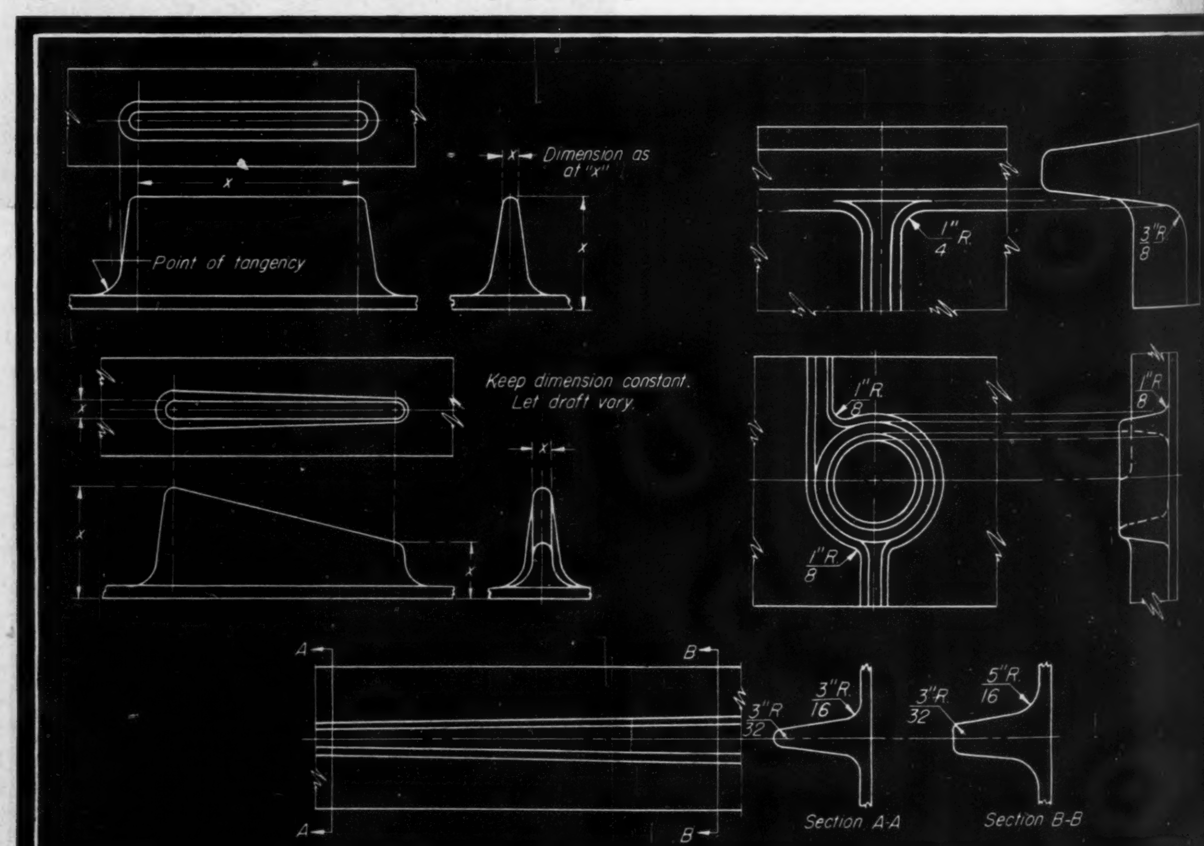


Fig. 1—Low, even friction, low expansion and corrosion resistance makes carbon-graphite an ideal material for face valve parts

Carbon-Graphite IN DESIGN

Fremont F. Ruhl
The United States Graphite Company

ACK of adequate information probably accounts for the fact that carbon and graphite materials often are not given sufficient consideration by design engi-s. It is the purpose of this article to give a simple ex-ation of some of the physical and chemical charac-tics of one specific type of carbon and graphite mate-known as "Graphitar", and cite actual established ap-ations, *Fig.* 1, to show how proper design can utilize favorable properties available.

OCESSING THE MATERIAL: This carbon-graphite mate-is composed of carbon and/or graphite particles bond-with carbon. In the first processing step the carbon and hite particles are mixed with a hydrocarbon bond and equently ground to a fine powder. Next this mixture essed in dies under high pressure to form molded s which then are baked in a controlled atmosphere ace at up to 3000 F to drive off all gaseous hydrocar-, carbonize the bond and yield carbon-graphite stock. arbon-graphite stock made from these components and essed in this manner has a set of physical and chem-characteristics unlike that of other materials. Com-atively strong in compression and transverse breaking ngth, it is weak in tensile strength, TABLE I, and has extremely low coefficient of linear expansion coupled a high coefficient of thermal heat transfer. It is highly resistant to reaction with all but the most oxidizing of chemicals, will not warp or distort under temperature variations and is light in weight. Perhaps the most valuable characteristics are hardness, good wearing qualities and non-scoring properties.

TOLERANCES IN PRODUCTION: The physical and chemical properties outlined must be considered in conjunction with the available methods for processing this material into a finished form. Molding of a powdered solid of this kind differs from that encountered with plastics. It is difficult to form irregular shapes in a die owing to lack of flow in the powdered solid during processing. For this same reason parts with undercuts cannot be die molded. Tolerance on die-made parts has been established as 1 per cent of the dimension on inside and outside diameters with a minimum of 0.010-inch and 10 per cent on the length or thickness.

High Accuracy Possible

Carbon-graphite can be finished to extreme accuracy. Grinding wheels of rather coarse grit, tungsten carbide tipped tools and industrial diamonds usually are used at high cutting speeds for finishing. For some special work high-speed tool steel cutters or drills are used. However,

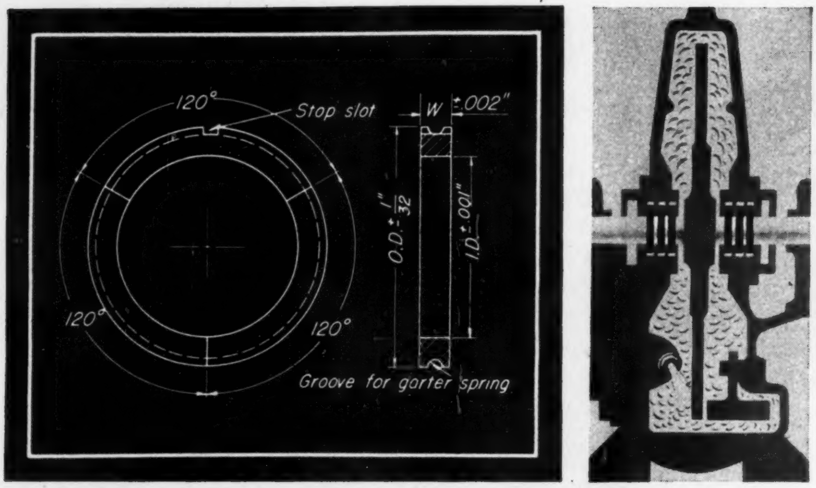


Fig. 2—Carbon-graphite steam turbine seals provide an effective labyrinth-action seal at 700 psi pressure and 825 F temperature

due to the inherent nature of the stock, the cutting edge on standard machine tools of this kind must be renewed often.

Finish tolerances on ground surfaces of plus or minus 0.00025-inch are not uncommon, while some flat surfaces lapped to a total tolerance of 35 millionths of an inch are in standard production. The high hardness, stability and low expansion rate of carbon-graphite all contribute to the ease of holding very accurate dimensions.

DESIGN: The design of carbon-graphite parts must suit the material in order to gain full advantage of its favorable properties. This can best be illustrated by established applications showing how the unfavorable qualities of carbon-graphite have been overcome through proper design.

TABLE I

Physical Characteristics of Carbon-Graphite Stock

Compressive Strength (psi)	18,000 to 37,000
Tensile Strength (psi)	1000 to 3000
Transverse Breaking Strength (psi)	3750 to 13 000
Scleroscope Hardness	80 to 100
Weight (lb per cu in.)	.0595 to .0672
Specific Gravity	1.7
Density (real)	2.00 to 2.26
Density (apparent)	1.65 to 1.86
Thermal Expansion (in./in./deg F) 65 to 625 F	.0000015
Thermal Conductivity	*
Coefficient of Friction, on steel	
Lubricated	.04
Not lubricated	.23
Porosity (% by weight)	
Standard untreated grades	4 to 8
Impregnated grades	(avg) .25
Electrical Conductivity (ohms per cu in.)	.0018
Melting Point	**
Working Temperature Range	
Neutral or reducing atmospheres	**
Air or oxidizing atmospheres (max., deg F)	600 to 650

*Ranges from slightly less than that of copper to more than that of cast iron.

**Will not melt or fuse. Volatilizes if heated to 6332 F.

SEALS: One of the first uses of carbon-graphite was developed by turbine engineers. In quest for a material that would withstand high rubbing speed (200 fps), high temperature (825 F) and high pressure (700 psi), it was found that carbon-graphite was the most stable, low-friction material that would provide a really satisfactory steam seal. Designed as shown in *Fig.* 2, this seal reduced leakage losses to one-tenth that of the old, space consuming labyrinth packing. This design is now used on steam turbines, turbo blowers, exhaust che gas fans, turbo electric generator se gas turbine auxiliaries.

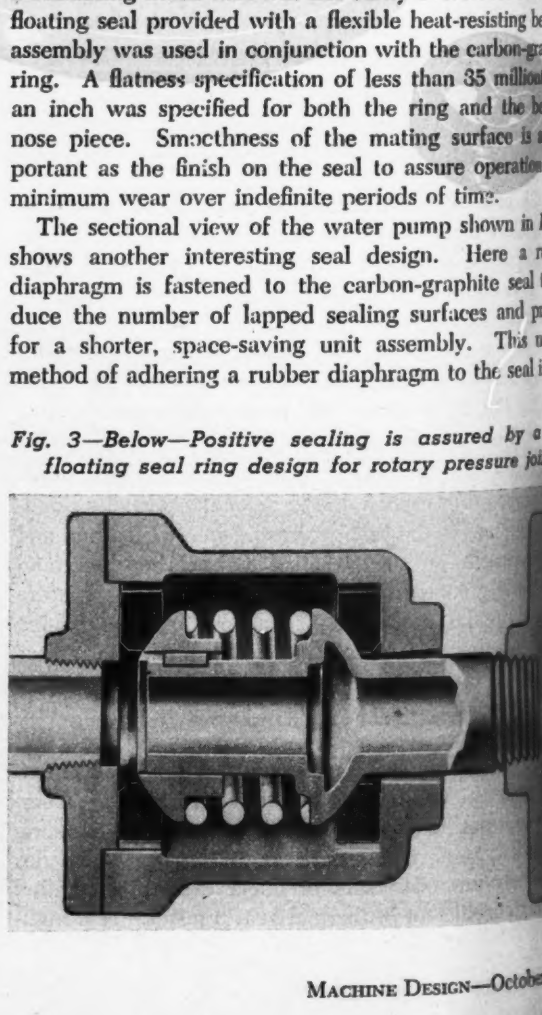
Steam turbine type seals, *Fig.* 2 made in segments to provide fo sembly without disturbing the shaft garter spring around the seal hold sections together, but exerts no pre on the shaft. Cross-sectional area of seal segments is so made as to pro an ample garter spring groove and a slot without weakening the ring s ture. Inside diameter fit takes into sideration the relatively high expa of the shaft at high temperature and low expansion of the carbon-gra under like conditions. A close fit is th fore not maintained on a cold or i turbine.

Unlike the partial sealing action steam turbine seal, rotary pressure joints, *Fig.* 3, use bon-graphite rings to form a positive, drop-tight seal of the best of seal designs, this rotary pressure joint carbon-graphite in compression as a free floating The rotating internal member can pivot angularly on spherical surface while the flat face does the sealing at the same time provides for lateral motion.

Greatest problem in the development of the fluid c ling was the seal, *Fig.* 4. Severe conditions of opera with temperatures up to 550 F and pressures as hig 90 psi at 1000 fpm on either SAE 10 oil or kerosene a stumbling block that was not easily overcome. The floating seal provided with a flexible heat-resisting bel assembly was used in conjunction with the carbon-grap ring. A flatness specification of less than 35 millionth an inch was specified for both the ring and the bel nose piece. Smoothness of the mating surface is im portant as the finish on the seal to assure operation minimum wear over indefinite periods of time.

The sectional view of the water pump shown in Fi shows another interesting seal design. Here a rub diaphragm is fastened to the carbon-graphite seal to duce the number of lapped sealing surfaces and pro for a shorter, space-saving unit assembly. This ne method of adhering a rubber diaphragm to the seal is

Fig. 3—Below—Positive sealing is assured by a floating seal ring design for rotary pressure joints



ible only on low-temperature and low-pressure applications. The rub- diaphragm member will not warp the sealing surface out of flat when nsion differentials are encountered with temperature variations. A sim- design principle cannot be used on a metallic bellows assembly if a ive drop-tight seal is desired because the expansion or contraction of metallic nose piece of the bellows in which the carbon-graphite is re- ed will warp the sealing surface.

A face type, high-speed grease seal that is manufactured as a unit is vn in *Fig.* 6. This unit uses a free-floating carbon-graphite seal in com- sion in conjunction with a synthetic rubber ring and garter spring. The rate of wear permits the use of a wave her type spring for the required thrust.

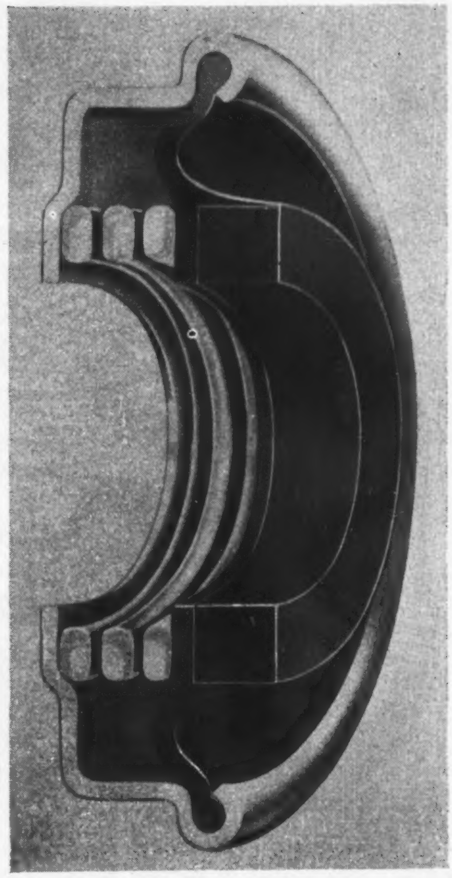


Fig. 5—Right—Rubber can be adhered directly to a carbon-graphite seal ring for low-temperature, low-pressure applications

ANES AND BEARINGS: Carbon-graphite s and bearings are used in aircraft pumps, 7, which handle fuel, water, alcohol or air ressures up to 50 psi and operate at 600 from −65 F to 150 F. The vanes do not ode, are light in weight, operate either dry ubricated by the fluid being pumped, are der than the original metal vanes, and only -fifth as heavy. If sharp edges are avoided wearing surfaces, the vanes will polish to an ideal fit. Such vanes cannot be ex- ted to seat-in satisfactorily from a square ce by wear on a sharp corner.

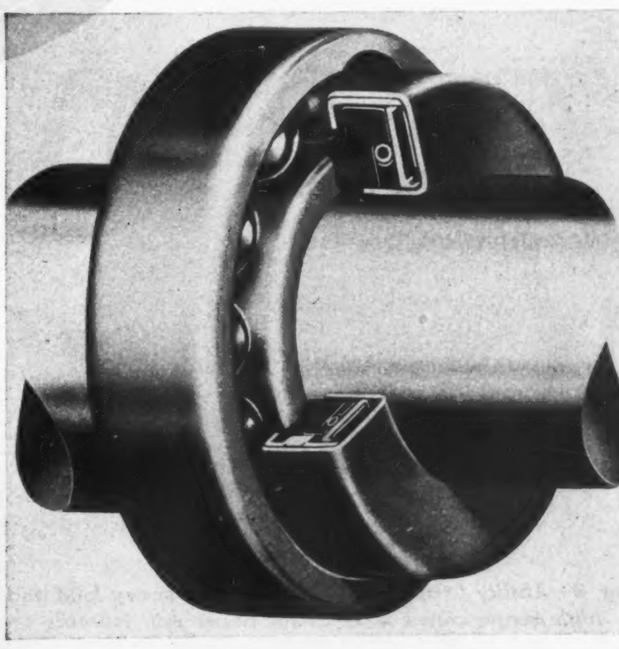


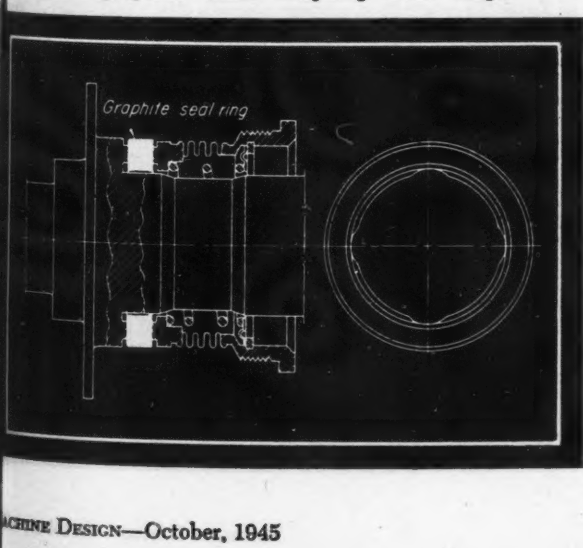
Fig. 6—Right below—Low friction characteristics avoid undue heating of the bearing raceway on face - type high - speed grease seals

Does Not Gall

A small metal chip or bit of foreign material ordinarily jam a pump equipped with tal vanes and complete, immediate failure ally results. Chips or bits of foreign material merely bed themselves into or chip a carbon-graphite vane hout causing pump failure.

Bearings on these pumps, *Fig.* 7, are also of carbon- phite material. General practice in replacing metal rings with carbon-graphite is to retain the same size somewhat greater cross-sectional area. Chamfers on edges minimize chipping of the bearings during as- bly and shrink fitting is recommended. Bearings with outside diameter of from 0.0005-inch to .0025-inch over housing bore size are assembled by merely dropping m into place in a hot aluminum body. An ordinary household electric roaster that permits temperature con- trol in the proper range of heat is used to expand the pump bodies. A shrink fit on the outside diameter is much more effective than a press fit and reflects in a more ac- curately controlled close-in on the inside diameter. Pre- determined bearing bores can take into consideration the 25 per cent to 100 per cent close-in of the shrink fit used.

.4—Below—Problems of high temperature, high pressure d high rubbing speeds are obviated by finely-finished carbon-graphite fluid coupling seal rings



Probably the best illustration of the unusual property of carbon-graphite bearings to run without the use of con-

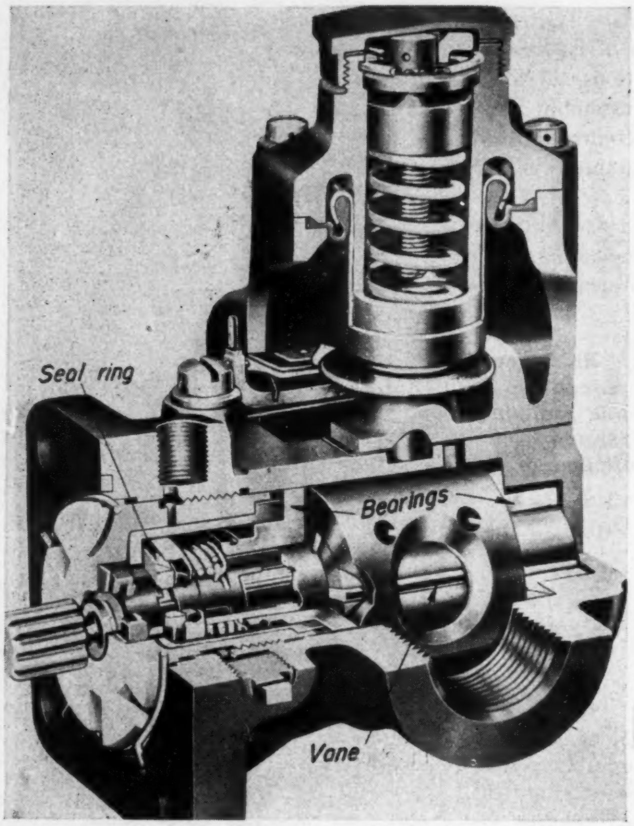


Fig. 7—Corrosion resistance, low expansion rate, light weight, and ability to operate without special lubrication are important reasons for pump applications

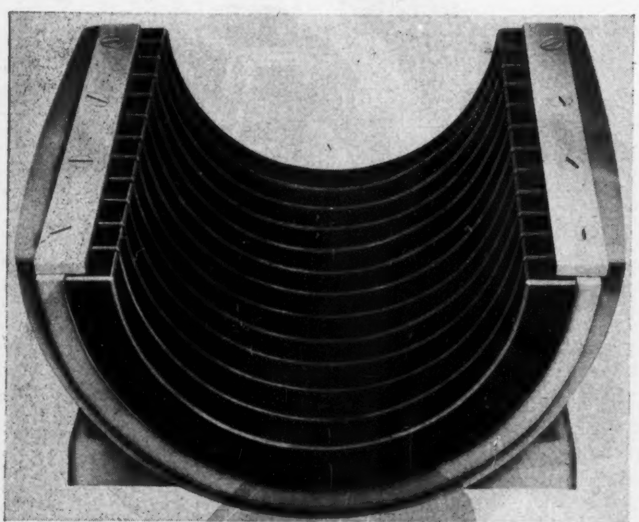


Fig. 8—Ability to operate bone dry under heavy load and high temperatures is ideal for paper mill journals

ventional lubricants is their use as journals for paper mill machinery. In *Fig* 8 is shown a simple design using carbon-graphite ring sections in series to form such a bearing. This journal supports heavy dryer rolls that weigh as much as 10 tons each. Steam introduced through a rotary pressure joint passes through the dryer rolls and thus creates a bearing temperature of about 230 F on these machines. Rubbing speed at the bearing ranges from 50 to 300 fpm. Eliminating the ever-present problem of undesirable grease and oil drippings, these bearings operate bone

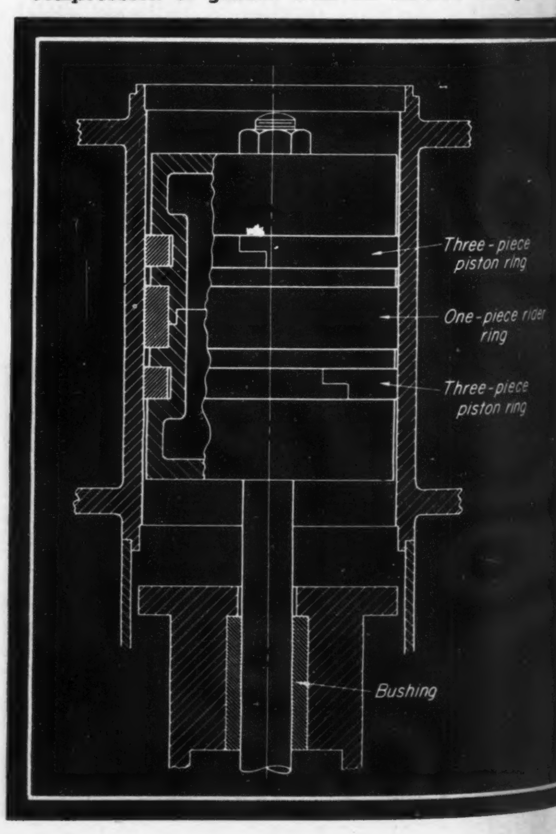
Full benefit of the chemical resistance and be properties of carbon-graphite was obtained in the u this material in machines for the textile industry. As bushings these bearings support immersion rollers wooden tank filled with bleach solution.

Unusual Applications: Carbon-graphite piston for nonlubricated compressors have broadened the fi application for these units. The ability of the materi run without oil has permitted the compression of gases as oxygen, carbon dioxide, methane, steam and to give an oil-free end product. Using a design with basic principles shown in *Fig.* 9, rings of either butt or joint style, in conjunction with a solid guide or wea ring, operate with good life. An auxiliary expander sp of metal supplies the necessary ring pressure.

Face type valve parts for meters dispensing gaso soap ingredients, gases and other chemical fluids are sh in *Fig.* 1. The favorable characteristics of carbon-gra ite, as with seals, are again used in these parts. A v using a flat metallic and carbon-graphite valve seat seal gas without the aid of a grease.

Use of carbon-graphite for end plates, supercha seals, clutch release bearings, elevator gibs, torque verter seals and spacer disks is well established. C cams, metal pouring funnels and molds, etc., have with success in certain applications but have yet to more fully investigated. When considering and spe ing this material the designer should bear in mind it is weak in thin sections and inherently brittle but using ample cross-sectional areas in compression extre ly favorable results can be obtained.

Fig. 9—Below—Carbon-graphite piston rings make possi compression of gasses with an oil-free end produ



MACHINE *Editorial* DESIGN

Reduce Costs Through Materials!

DESIGNERS of machines have every reason to be proud of their record during the war in the conservation and substitution of materials. Ingenuity of the highest order was displayed in meeting the requirements of the armament program.

Similar resourcefulness will be essential, though for a far different purpose, in the days ahead. The question of cost, for instance, which was of relatively little moment in wartime design, is destined to play an increasingly important part in the recovery period. Design, more than ever before, will be good design only if the resulting cost of manufacture permits the maintenance of high production based, in turn, on the ability of vast numbers of potential purchasers to buy.

It is fortunate, if for this reason alone, that the choice of materials at the disposal of the designer has widened tremendously due to wartime innovations. Various grades of aluminum, steel alloys and plastics, for example, will be available in such quantities that the increased use to which they undoubtedly will be put should facilitate many refinements in design that can well prove, in the end, to be economically sound.

Saving of weight, particularly with regard to the use of aluminum and magnesium, is a case in point. The lighter metals, though not by any means a cure-all, have a wonderful chance to come into their own. For such divergent reasons as their desirability for fast-moving machine parts and for transportation by aircraft freight, they now present opportunities for applications on which their use in prewar days was unwarranted.

In all the ramifications incident to the future selection of materials of design, fabrication or "processability" will call for increasing consideration. The possibility of reduced costs again is a factor that warrants intense study due to the potentially higher labor charges that must be offset.

With the current emphasis on materials it is regretted that, due to the limitations imposed during the war, it was impossible this year for MACHINE DESIGN to schedule the annual directory of materials customarily published in each October issue.

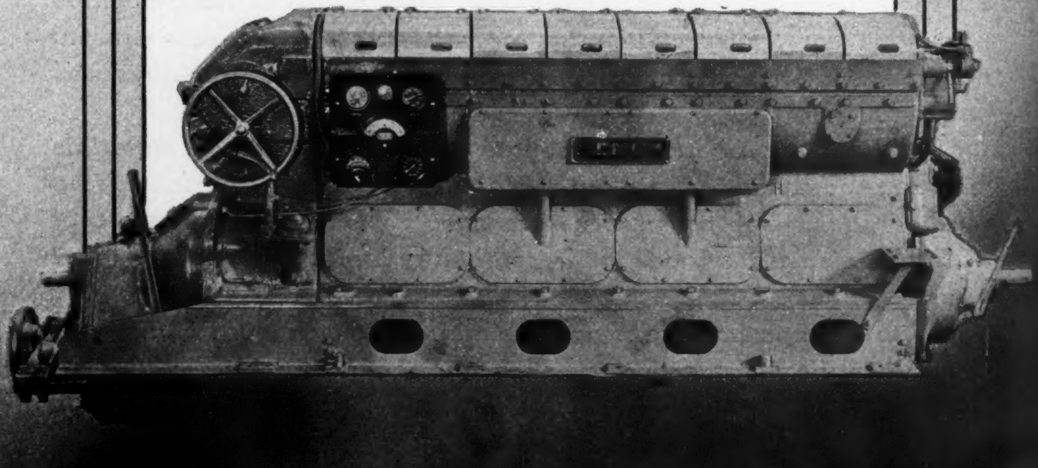
L. E. Jermy

Marine Diesel

Of the four-stroke cycle type and designed for heavy-duty, medium-speed operation, this new marine diesel of the Joshua Hendy Iron Works is air starting and direct reversing, and has overhead camshaft, unit fuel pumps and injectors, and full pressure lubricators. Cast iron, monoblock construction is employed with under-hung crankshaft, removable cylinder liners, and auxiliary drives arranged at either end.

Crankshaft, dynamically balanced, is cast iron with hollow crank pins and main journals. Pistons are cast iron and of simple design with four compression and two oil-control rings. In each individually cast cylinder head are the intake and exhaust valves, the unit pump and injector, the air-start valve, and an indicator connection. The two-inch diameter, ground-steel camshaft is fitted with forged, hardened and polished steel cams. There are three cams per cylinder; intake, exhaust, and a third performing the dual function of fuel injection and air starting.

Fresh-water cooling is employed, effectively reducing rust, scale or chemical deposits in water jackets and materially reducing maintenance costs. Use of unit fuel pumps and injectors, operating in conjunction with the overhead camshaft, effectively reduces the number of moving parts required.



Stiffness Gage

Used for determining the stiffness of materials such as laminated plastic, cardboard, sheet metal and wire, this instrument, manufactured by Taber Instrument Corp., employs a calibrated weighing system of the pendulum type. A driven disk, at the center of the calibrated dial, is actuated by a capacitor motor which is controlled by three microswitches and operated by a single three-way knob. Specimen is mounted on the pendulum and loaded with specified weights. Flexing power is applied to the lower end of the specimen by rollers attached to the power driven disk, and the torque resulting deviates the pendulum from the vertical. A special motor winding enables the armature to lock at any desired setting to permit the operator to make dial readings. Entire pendulum assembly, except the calibration weight, is aluminum alloy, keeping inertia and bearing friction at a minimum. All exposed parts are finely finished aluminum or stainless steel.

(New machines listed on Page 200)

PROFESSIONAL VIEWPOINTS

MACHINE DESIGN welcomes comments from readers on subjects of interest to designers. Payment will be made for letters and comments published

". . . . new gear data found"

To the Editor:

It may interest the readers of MACHINE DESIGN that up-to-date and accurate data on gear efficiency can be found in a book which was mentioned as a reference in the article "Worm Drive 'Jitters' Can Be Avoided" by S. J. Mikina published in the March issue. The book "Gears" by H. E. Merritt was published by Sir Isaac Pitman and Sons, Ltd., London 1943.

In his book the author states that because of our present imperfect knowledge of the coefficient of friction under varying conditions of speed, exact calculations of gear tooth efficiencies on theoretical grounds are impracticable. It is therefore unprofitable to attempt to estimate the efficiency of spur, bevel and helical gears on other than broadly comparative lines using mean values of the coefficient of friction found by deduction from measured efficiency values. Such values thus obtained range from 0.06 to 0.08. By analogy (with results obtained un conditions representing worm gears), the effect of incr ing the sliding velocity is to reduce the value of the efficient of friction. Present data available do not jus the introduction of such a refinement.

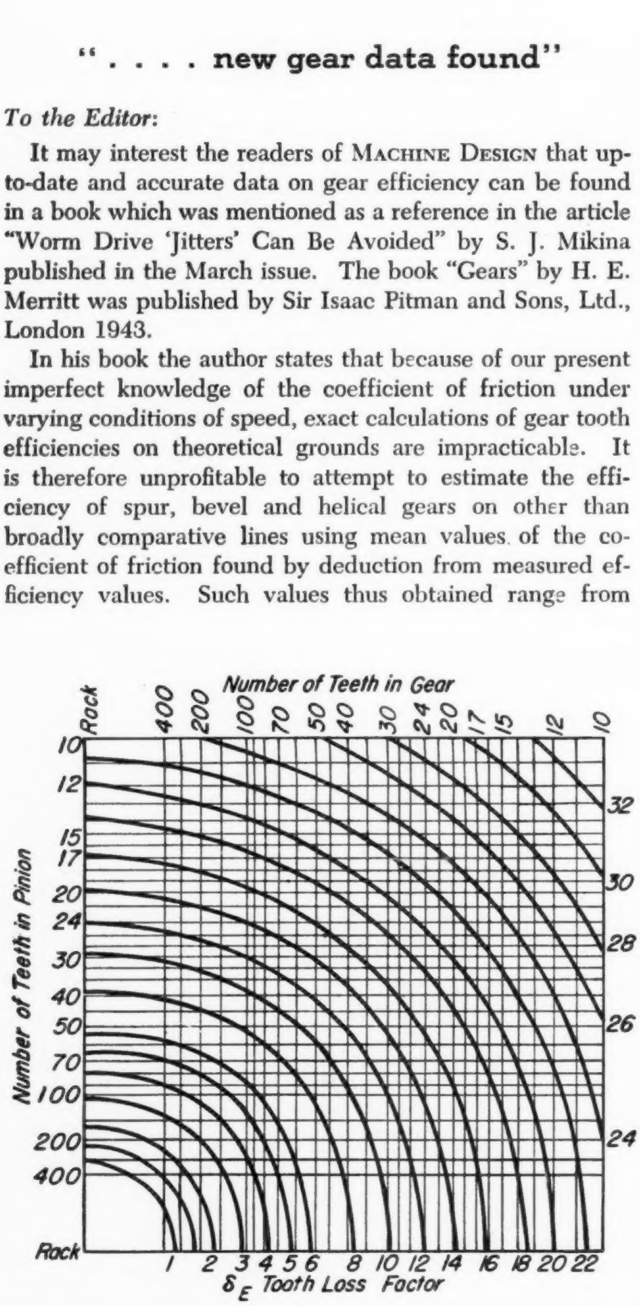


Chart of frictional power loss factors for gears and pinions in any possible selected ratio

Losses in power transmission with spur gears are usu made up of losses due to sliding friction in the gear te oil churning and friction loss in the bearings. These lo are represented by a single frictional coefficient of frict For ball or roller bearing mounted steel gears of stand material, machining and heat treatment, this frictio coefficient may be taken as

$$\mu = 0.08$$

The efficiency is then

$$E = 100 - \mu\delta_E$$

where δ_E is the tooth loss factor for a pressure angle of degrees. The accompanying chart gives this tooth l factor for all possible gear ratios.

For any pressure angle other than 20 degrees, the to loss factor has to be corrected according to the formula

$$\delta_E' = \delta_E \times 0.643 \times cosec\ 2\psi$$

where ψ is the required pressure angle and δ_E' is the c rected tooth loss factor for any desired pressure angle. T latter can then be substituted for δ_E in the formula for efficiency.

—H. W. HAM
York,

". . . series is very timely"

To the Editor:

Your recently begun series of articles on product processes and their influence on design is very timely view of our present nation-wide reconversion progr which will without doubt entail the entire redesigning the most commonly used and widely produced parts.

In the writer's opinion the article on broaching eminently satisfactory in all of its outlook. I was glad

that discussions on tolerances which may be obtained all types of broaching were included. All too often cles of this type fail to disclose such information.

t is hoped that this series of articles, besides including more commonly used processes, will cover some of the e recent ones. I refer, particularly to tumbling barrel shing, centerless grinding and similar new developnts. It is realized that the centerless thread grinding cess is limited and specialized, but a complete article barrel finishing would find a proper place in the series would also have high information value.

our production series, as I see it, discusses the submainly from a cost-reducing or economy angle. This n excellent program, but to it may I add the great antage afforded the machine designer in knowing e processes both qualitatively and quantitatively, not y as expedient to reducing costs in production, but e so in the proper evaluation of processing as it affects ign as a whole.

—NORMAN W. TAYLOR
The Warner & Swasey Co.

ACHINE DESIGN plans to cover all production processes re the field of application is sufficiently wide and conration in design is of primary importance.—ED.

. . . materials selection important"

the Editor:

The Materials Work Sheets presented in MACHINE SIGN give the kind of information in which we are interested. Through such published data, augmented by our own research facilities, we attempt to keep posted on new materials and their applications.

Major products of our Indianapolis operations are chains, sprockets and antifriction bearings. Naturally, the selection of materials is of major importance. In connection with the application of materials and their usage in component parts of power transmission equipment, we have found standards with respect to test-bar strengths very essential in the successful handling of the various materials.

—C. R. WEISS, *Chief Engineer*
Ewart Plant, Link-Belt Co.

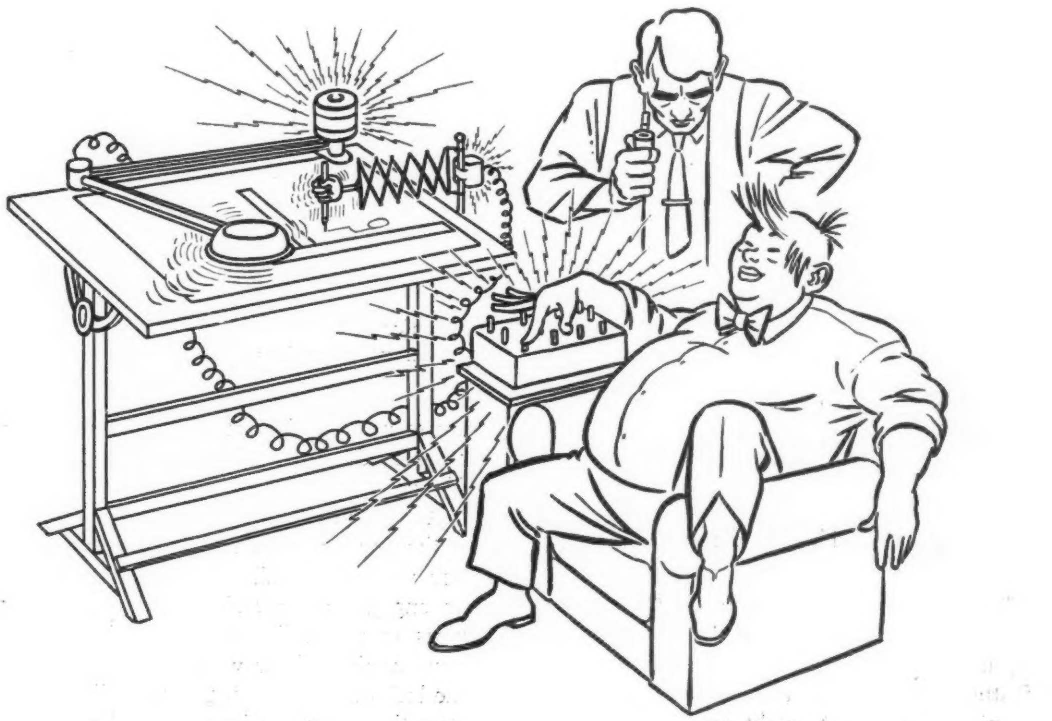
". . . of much interest"

To the Editor:

We have read your article "Production Processes—Their Influence On Design—Part I—Broaching" in the July issue of MACHINE DESIGN. The article was of very much interest to members of our organization, and we would appreciate your forwarding us six copies of this article if they are available.

—C. P. LONSKEY, *Broach Engineer*
American Broach & Machine Co.

MACHINE DESIGN is happy to provide such information for designers and welcomes their comments and suggestions. Copies of the article have been forwarded.—ED.

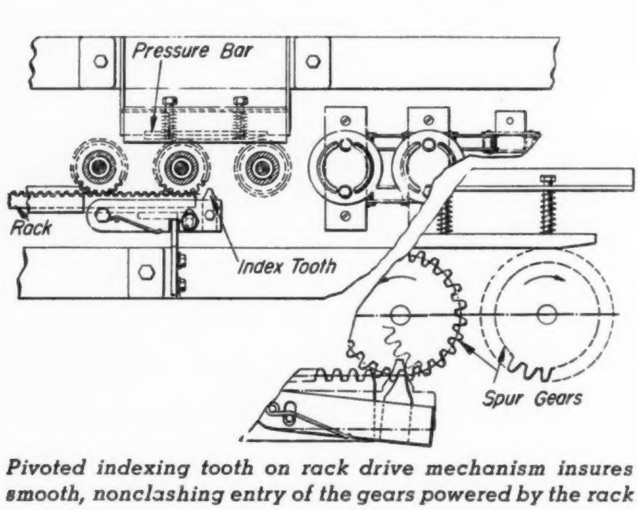


"See here, Briskbottom, don't you think you're carrying this remote control idea too far?"

Noteworthy Patents

Assures Correct Tooth Engagement

A SIMPLE device which affords positive, nonclashing engagement of gears as they traverse a stationary section of rack to rotate or power a continuous series of work spindles is shown in the accompanying illustration.



Pivoted indexing tooth on rack drive mechanism insures smooth, nonclashing entry of the gears powered by the rack

Covered by patent 2,376,161 recently assigned to the Selas Corporation of America, it provides an effective means for rotating cartridge cases and other bodies as they are passing through a furnace chamber for a uniform heat treatment.

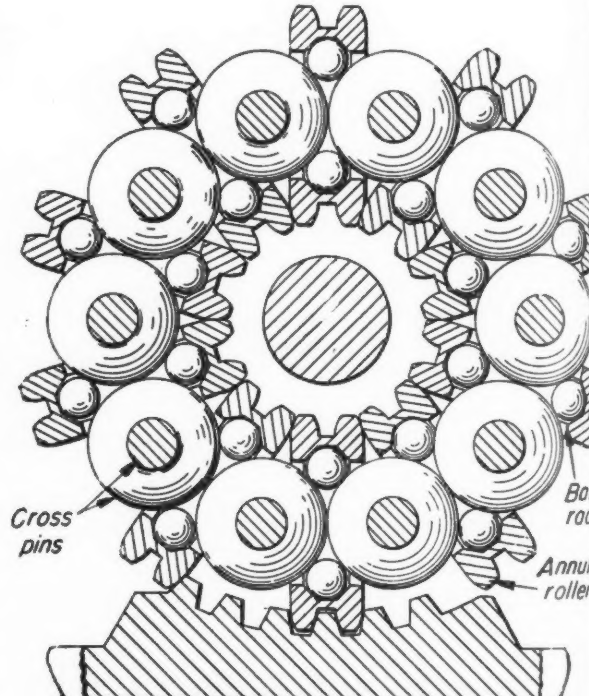
In order to align or mesh a nonrotating gear as it approaches a stationary section of rack, a pivoted index tooth is utilized. The pressure bar shown first induces a rotation of the approaching gear opposite that of the normal direction to insure smooth entry of the index tooth. As the index tooth engages it starts proper rotation of the gear and deflects downward thus aligning the gear teeth with those of the rack. Once the gear is rack driven, the index tooth again assumes normal position to engage the next gear in the series.

The device is equally effective for other types of gears such as helical, bevel, spiral, etc. It can be used to similar advantage in mechanisms wherein the rack is the moving element and the geared spindles are stationary or where both elements move simultaneously.

Worm His High Efficiency

RECENTLY assigned to the Electrolux Corp. is patent 2,378,891 covering a novel and distinct improvement in worm gearing. Low friction and increased efficiency are key features of a rolling contact wormwheel which may be employed with both right and left-hand worms alike and with widely varying helix angles.

Shown in the accompanying illustration, the gear is signed for operation in conjunction with a conventi Hindley or hourglass type worm. Rotation of the w in the appropriate direction creates a counterclock rotation of the wormwheel. Pressure of the worm te is transmitted substantially normal to the center plane annular rollers on the wormwheel and is carried thro ball races to spherical cross pins. Riveted securely to members of the wormwheel, all the spherical cross p



Annular grooved rollers replacing ordinary worm wh teeth produce low rolling friction and high efficienc

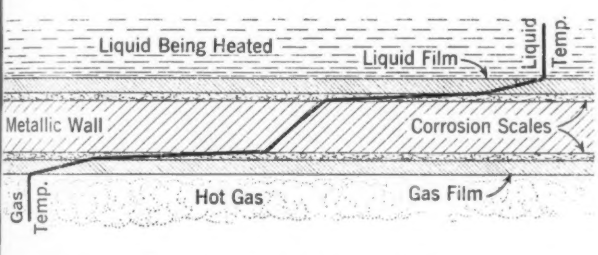
are so positioned as to be in tangential contact with ea other to distribute the driving load over a large numb of pins.

As the worm revolves, the annular-toothed rollers tu in the opposite direction creating only a minor rolling fr tion within the ball races. Contact between the face an engaged roller and that of one directly following i parts to that roller a peripheral speed substantially t same as that of the worm as the two engage. Owing the lack of high rubbing speeds all parts of the wheel a even the worm can be made of hardened steel to achie a considerably longer operating life.

Effect of Material on Heat Transfer Rate

FOR PROPER design of cooling systems, heat exchangers, and other equipment involving heat flow through metal walls, the effects of materials and wall thicknesses on the overall heat transfer rate must be carefully considered. The necessary information is contained in this data sheet, which includes formulas for determining overall heat transfer rate, thermal conductivities of metals and alloys commonly used for heat exchange, and charts facilitating the calculation of overall rates.

In the accompanying figure is shown the general manner in which temperatures vary for a typical case of



a metallic wall separating fluids at different temperatures. The rate of flow is given by the general formula

$$H=U\,A\,\Delta T \quad \text{(1)}$$

where H=total rate of heat flow, Btu per hr, U=overall rate of heat transfer (overall conductance), Btu per hr per sq ft per deg F, A=surface area available to transfer heat, sq ft, and ΔT=mean effective temperature difference between the hot and cold fluids, deg F. In designing a piece of equipment the information desired is the area A, which may be obtained from Equation 1 if the other quantities are known.

To compute the effective temperature difference, ΔT, the operating conditions must be known or estimated. In general the hot fluid enters and leaves at different temperatures and so does the cold fluid, in which case the mean temperature difference (M.T.D.) must be computed from the maximum and minimum temperature differences between hot and cold sides. Depending upon conditions, either the arithmetic or logarithmic M.T.D. may be used. The arithmetic M.T.D. is given by the equation

$$\Delta T_a=\frac{\Delta T_1+\Delta T_2}{2} \quad \text{(2)}$$

The charts and information from which this data sheet has been prepared were furnished through the courtesy of The International Nickel Co. Inc.

TABLE I

Thermal Conductivity of Metals and Alloys

Material	Conductivity* Btu/hr/sq ft/°F/in
Silver	2,900
Copper	2,680
Aluminum (2S)	1,570
Red Brass (85-15)	1,100
Yellow Brass (65-35)	830
Zinc	770
Admiralty Brass	760
Ingot Iron	470
Mild Steel (SAE 1020)	460
Tin	455
Nickel	420
Lead	240
Nickel Silver (18 per cent)	230
Silicon Bronze	225
Cupro Nickel (70-30)	200
Monel	180
Stainless Steel (Type 430)	155
Stainless Steel (Types 304, 316, 321)	105
Inconel	104

* These values are for a temperature range of 32 to 212 F. and are taken from published data. Values at other temperature levels are slightly different. Individual measurements may indicate values different than those listed since for any metal or alloy this property varies from melt to melt and with different forms, tempers, etc.

and the logarithmic M.T.D. by the equation

$$\Delta T_l=\frac{\Delta T_1-\Delta T_2}{\log_e\dfrac{\Delta T_1}{\Delta T_2}} \quad \text{(3)}$$

where ΔT_1 = greater temperature difference and ΔT_2 = lesser temperature difference between hot and cold sides. When ΔT_1 and ΔT_2 are relatively close together the arithmetic M.T.D. may be used without serious error. When they are far apart or whenever greater accuracy is desired the logarithmic should be used.

Determination of the overall conductance, U, involves consideration of the thermal conductivity and thickness of the metallic wall, and the conductances of the gas, vapor or liquid films on either side of the wall as well the conductances of scale or corrosion deposits. The equation for U is

$$U=\frac{1}{\dfrac{X}{K}+\dfrac{1}{h_1}+\dfrac{1}{h_2}+\dfrac{1}{h_3}+\dfrac{1}{h_4}} \quad \text{(4)}$$

where K = conductivity of the metal, Btu per hr per sq ft per deg F per inch thickness (see TABLE I), X = thickness of metallic wall, in., and h_1, h_2, h_3, and h_4 are the conductances of the surface films and corrosion scales or deposits, TABLE II. Combining the conductances of the films and deposits, the overall film conductance, U_f Btu per hr per sq ft per deg F, may be written

ENGINEERING DATA SHEET

$$U_f=\frac{1}{\frac{1}{h_1}+\frac{1}{h_2}+\frac{1}{h_3}+\frac{1}{h_4}} \qquad (5)$$

Equation 4 then may be written

$$U=\frac{1}{\frac{X}{K}+\frac{1}{U_f}} \qquad (6)$$

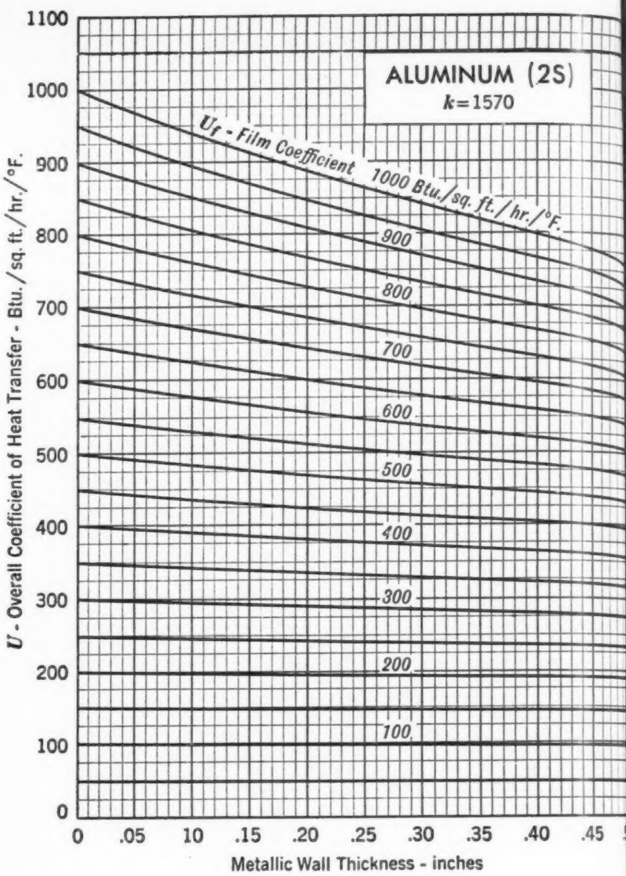
Charts based on Equation 6 are presented on Pages 164, 165 and 166 using value of K appropriate to the various metals and alloys. In the original design of equipment it is necessary to estimate U_f, using Equation 5 and the best information available on the separate

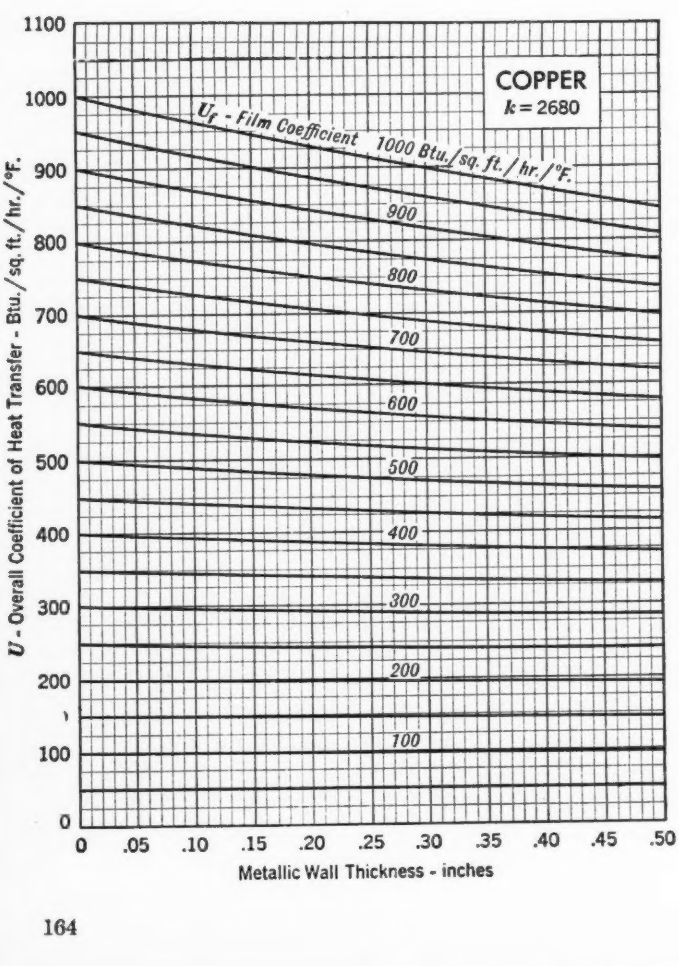
TABLE II

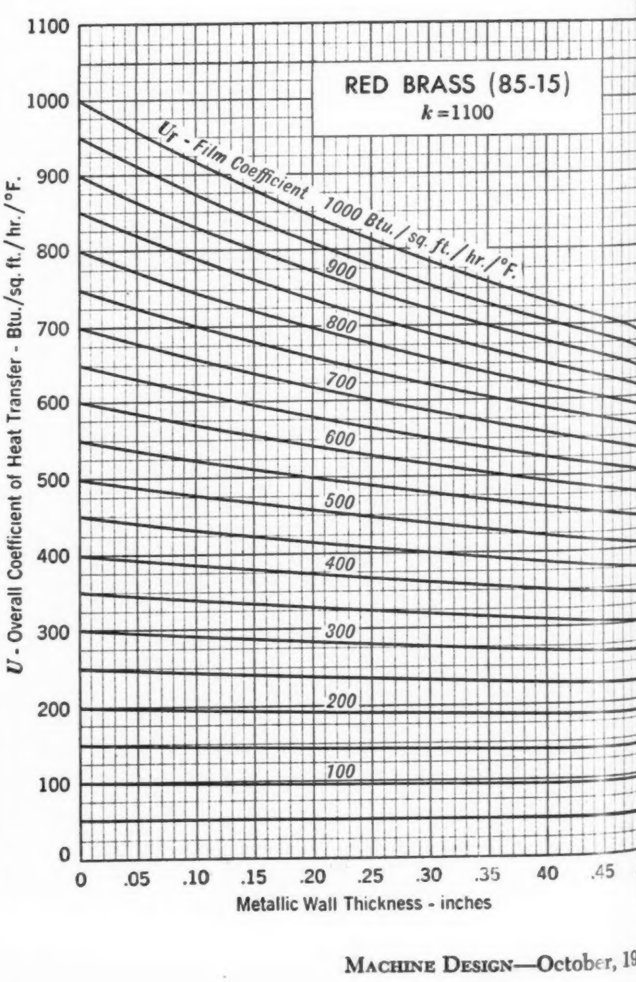
Comparison of Conductance Ranges

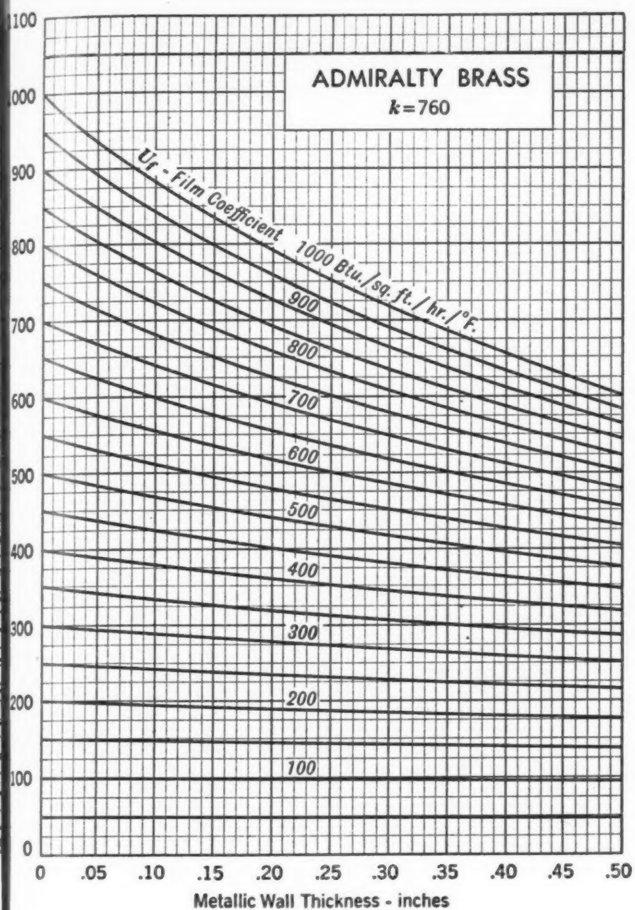
Nature of Obstruction	Conductance Range Btu/hr/sq ft/°F.
Metal wall	
1 in. thick	75 to 3,000
0.025-in. thick	3,000 to 120,000
Condensing vapor	1,000 to 4,000
Evaporating liquid	500 to 2,000
Liquid being heated	50 to 500
Liquid being cooled	40 to 400
Gas being heated	5 to 50
Gas being cooled	5 to 40
Corrosion scale	5 to 20

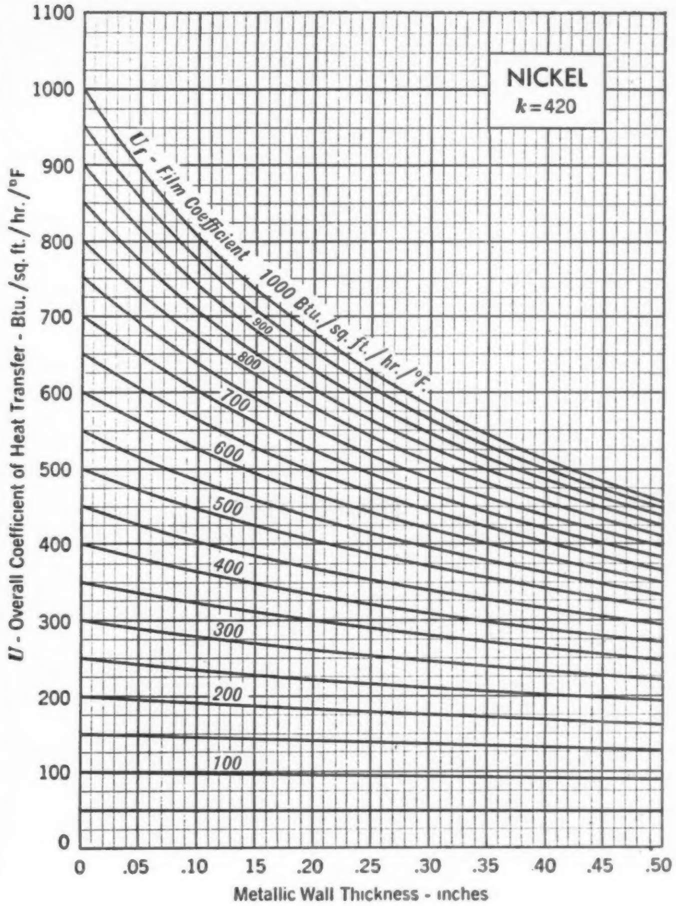
film and deposit conductances. The value of the charts, therefore, lies in enabling the designer to compute the effect of changing either the nature or the thickness, or both, of the metal used in equipment for which U_f is known fairly accurately.

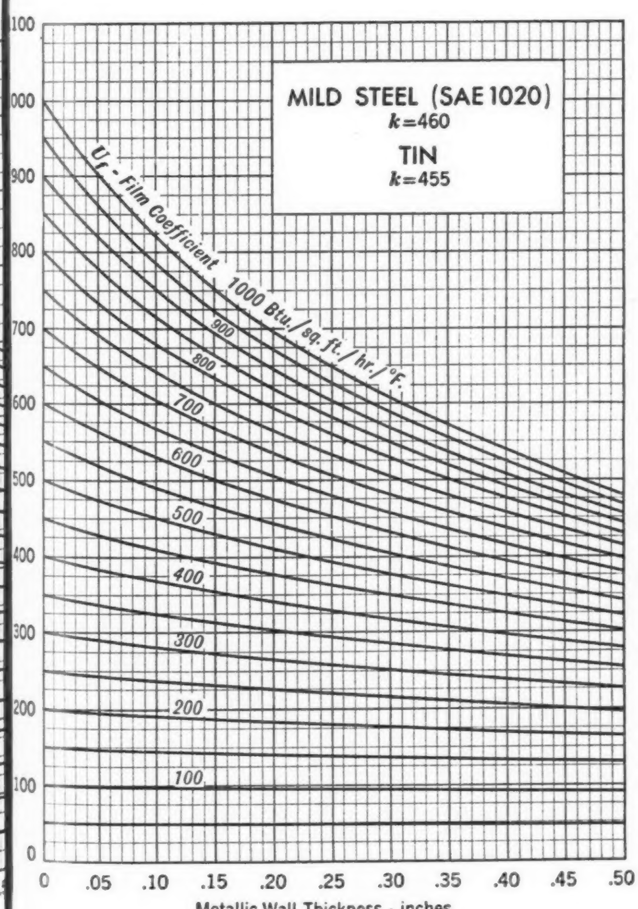


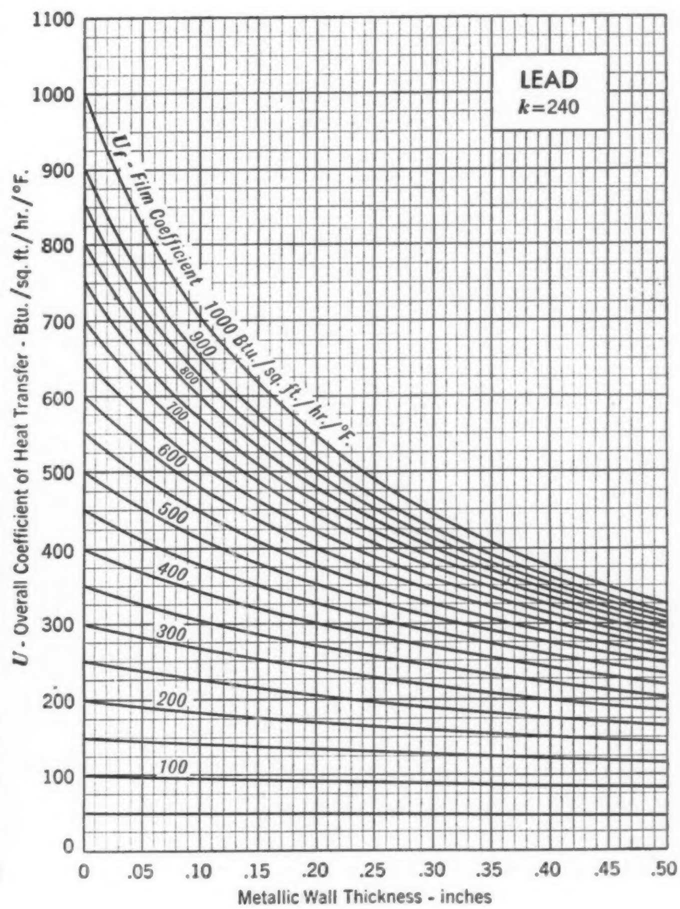




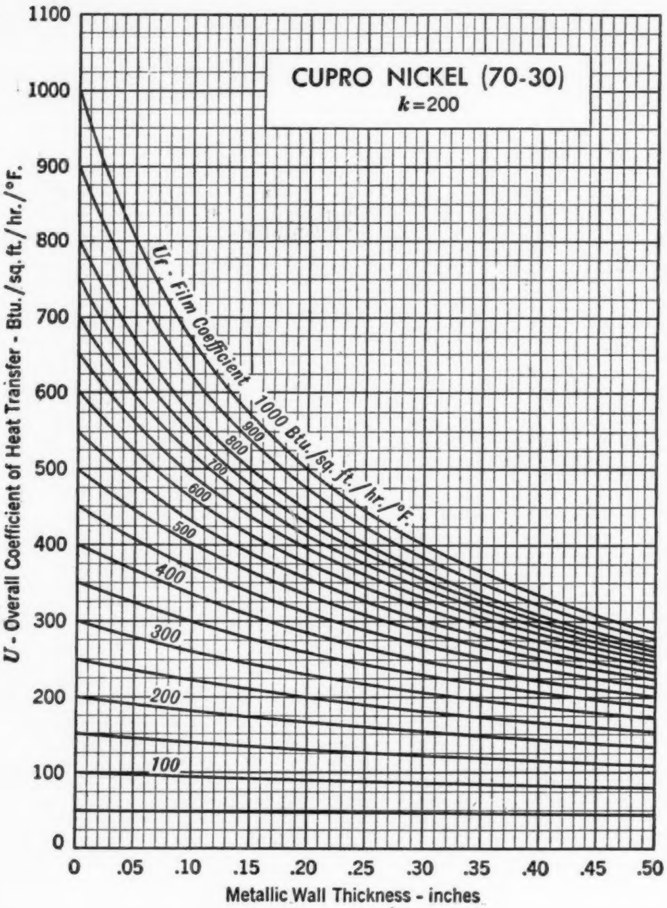

ADMIRALTY BRASS
k=760
U_f - Film Coefficient 1000 Btu./sq. ft./hr./°F.
900
800
700
600
500
400
300
200
100
Metallic Wall Thickness - inches

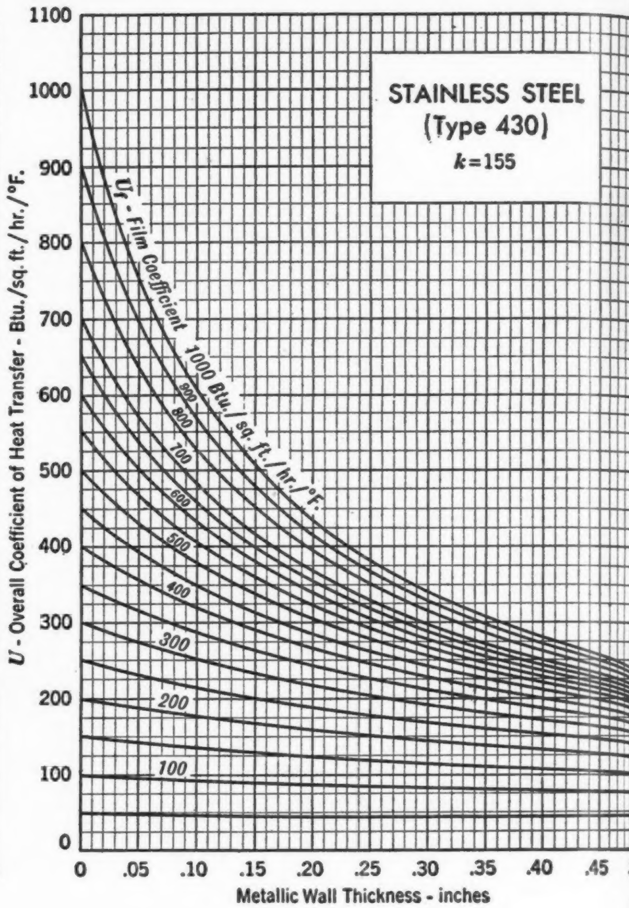

NICKEL
k=420
U - Overall Coefficient of Heat Transfer - Btu./sq. ft./hr./°F
U_f - Film Coefficient 1000 Btu./sq. ft./hr./°F.
900
800
700
600
500
400
300
200
100
Metallic Wall Thickness - inches

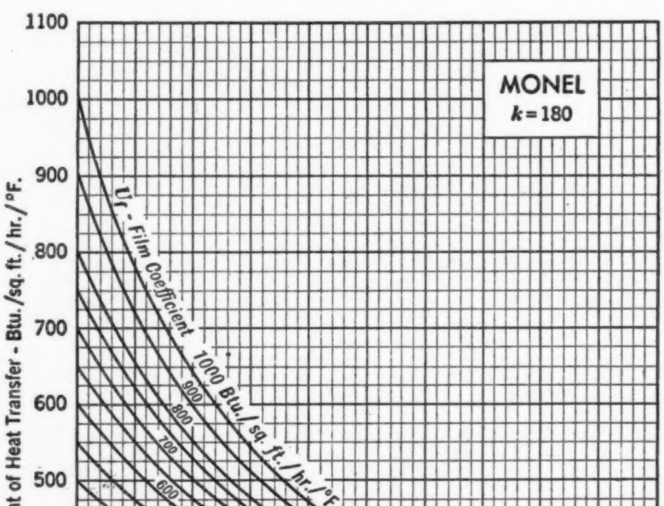

MILD STEEL (SAE 1020)
k=460
TIN
k=455
U_f - Film Coefficient 1000 Btu./sq. ft./hr./°F.
900
800
700
600
500
400
300
200
100
Metallic Wall Thickness - inches

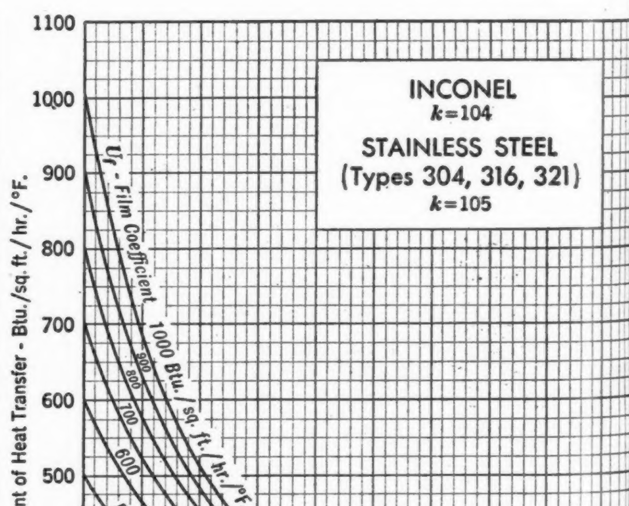

LEAD
k=240
U - Overall Coefficient of Heat Transfer - Btu./sq. ft./hr./°F.
U_f - Film Coefficient 1000 Btu./sq. ft./hr./°F.
900
800
700
600
500
400
300
200
100
Metallic Wall Thickness - inches

ENGINEERING DATA SHEET









MACHINE DESIGN'S

MATERIALS WORK SHEET

FILING NUMBER
7.01

Cast Nickel Alloy Steels

ASTM SPEC. NOS.: A148-44, Grades B1, B2, B3, C1, C2 and C3
A157-44, Grades C4 and C11
A217-44T, Grade WC4

Specifications of the American Society for Testing Materials (ASTM) for Cast Nickel Alloy Steels generally fix only the *minimum* mechanical properties. Properties higher than those listed can be obtained by varying the chemical compositions and by subjecting cast parts to various heat treatments.

It is suggested that the designer select the steel to be used from the standard (ASTM) specifications and, after acquainting the foundry with any additional properties required in a given part, leave the compounding of the steel and recommendations for its heat treatment in the hands of a competent foundryman.

PROPERTIES PRESCRIBED IN ASTM SPECIFICATIONS

ASTM ecification No.	Class	Heat Treatment*	Tensile Strength (min, psi)	Yield Strength (min, psi)	Elong. in 2 Inches (min, %)	Red. of Area (min, %)
		Alloy-Steel Castings for Structural Purposes				
148-44	B1	A or N or N. T.	85,000	55,000	22	40
148-44	B2	A or N or N. T.	90,000	60,000	22	45
148-44	B3	A or N or N. T.	100,000	65,000	18	30
148-44	C1	N or Q. T.	90,000	65,000	20	45
148-44	C2	N or Q. T.	120,000	100,000	14	35
148-44	C3	N or Q. T.	150,000	125,000	10	25
		Alloy-Steel Castings for Valves, Flanges and Fittings for Service at Temperatures from 750 to 1100 Degrees Fahr.				
157-44	C4	A or N. T.	100,000	65,000	18	30
157-44	C11	A or N. T.	100,000	65,000	18	30
		Alloy-Steel Castings Suitable for Fusion Welding for Service at Temperatures from 750 to 1100 Degrees Fahr.				
217-44T	WC4	A or N. T.	80,000	55,000	20	35

*N—Normalized, A—Full Annealed, N.T.—Normalized and Tempered, Q.T.—Quenched and Tempered.

CHARACTERISTICS

ast steels containing 0.5 to 5.0 per cent nickel, with or hout other alloys, are among the oldest in the alloy cast l field. Nickel imparts strength, toughness, and to a er degree, hardness, without decreasing ductility protionally. Excellent dynamic properties, i.e., resistance impact and fatigue stresses at normal and low temperas, are obtained with these steels. Nickel alloy steels are ter adapted for heat treated castings of large section than are the plain carbon steels. Certain of these steels respond fully to mild quenching in air.

Nickel Cast Steels: In the plain nickel cast steels, nickel content usually is between 2 and 3 per cent. When a higher nickel content is used the carbon content is decreased below the usual level of 0.30 per cent, since the high-carbon, high-nickel combination has considerable hardening power. A popular grade is the low-carbon, 2 per cent

MACHINE DESIGN is pleased to acknowledge the collaboration of the Steel Founders' Society of America in this presentan. Data included are abstracted from the Society's *Steel Castings Handbook*.

LOW-CARBON, 2% NICKEL CAST STEELS

Double normalized, 1725 F, 1525 F and tempered 1100 F

(normal expected values)

Composition* (%) C	Composition* (%) Ni	Tensile Strength (psi)	Yield Point (psi)	Elong. in 2 Inches (%)	Red. of Area (%)	Izod Impact (ft lbs)	Brinell Hardness No.
0.14	2.00	72,600	44,500	30.3	61.2	60	146
0.15	2.15	73,200	45,000	30.0	59.0	..	...
0.16	2.08	75,000	47.500	30.8	59.5	..	153
0.17	2.12	79,400	49,500	31.0	60.0	59	...
0.18	2.20	80,250	51,000	29.5	58.5	60	165
0.19	2.16	82,300	51,700	28.1	55.5	56	...
0.20	2.07	81,500	51,000	29.0	56.0	57	...
0.21	2.22	83,000	53,000	28.2	54.0	55	173

*Manganese 0.65 to 0.95, Silicon 0.30 to 0.40, Phosphorus and Sulphur below 0.05.

LOW-CARBON, 1 to 4.95% NICKEL CAST STEELS

Normally Expected Sub-Zero Impact Properties and Room-Temperature Tensile Properties

(double normalized and tempered at 1200 F)

Room-Temperature Properties					Charpy Impact (ft lbs)								
					Keyhole Notch				Vee Notch				
Composition† No.	Tensile Strength (psi)	Yield Point (psi)	Elong. in 2" (%)	Red. of Area (%)	70 F	−100 F	−150 F	−200 F	70 F	−50 F	−100 F	−150 F	−200 F
1	59,500	41,500	34.5	63.0	39-41	16-21	2-3	......	73	23	8	2	1
2	69,000	50,200	37.5	67.5	37-41	19-18	16-15	7½-2½	68	57	13	5	4
3	76,800	61,200	33.0	55.5	30-32	21-19	17-17	12-4	52	26	15	8	6
4	79,500	53,500	32.0	60.0	29-33	23-24	20-15	20-17	74	37	27	15	10
5	71,500	48,000	35.0	65.6	36-32	26-26	18-16	19-16½	65	34	22	13	6
6	90,200	48,200	26.0	45.5	30-35	20-18	19-15	10-8½	54	54	15	6	4

†Comp. 1: C—0.12, Mn—0.65, Si—0.35, Ni—1.00, Al added—0.080. Comp. 4: C—0.13, Mn—0.65, Si—0.35, Ni—3.50, Al added—0.0[illegible]
Comp. 2: C—0.14, Mn—0.65, Si—0.35, Ni—2.00, Al added—0.080. Comp. 5: C—0.10, Mn—0.65, Si—0.35, Ni—4.06, Al added—0.08
Comp. 3: C—0.15, Mn—0.58, Si—0.30, Ni—2.90, Al added—0.016. Comp. 6: C—0.11, Mn—0.64, Si—0.34, Ni—4.95, Al added—0.0[illegible]

nickel steels in which the carbon content usually is below 0.20 per cent. When given the recommended heat treatment of double normalizing followed by tempering, the normal expected values for increasing carbon and similar nickel contents will be approximately those indicated in the table "Low-Carbon, 2% Nickel Cast Steels".

A stronger steel is obtained from the medium-carbon (0.25 to 0.30 per cent carbon), 2 per cent nickel analysis. Mechanical properties normally expected from this steel following a normalizing and tempering heat treatment are as listed in the table "Medium-Carbon, 2% Nickel Cast Steels". As indicated by values shown in the table "Low-Carbon, 1 to 4.95% Nickel Cast Steels", addition of nickel to cast steel results in the retention of favorable impact values at sub-zero temperatures.

Nickel-Manganese Cast Steels: Manganese added to nickel cast steel produces an alloy of increased hardness and strength. These steels are moderate in cost and offer excellent mechanical properties after simple heat treatment. While they generally are known and used as air-hardening steels, there are instances where they are given the liquid quench and temper treatment. Most frequently used chemical ranges in this series are: Carbon 0.26 to 0.33, nickel 1.25 to 1.50, and manganese 1.25 to 1.65 per cent. Normally expected properties of nickel-manganese cast steel in these chemical ranges are given in the table "Nickel-Manganese Cast Steels".

MEDIUM-CARBON, 2% NICKEL CAST STEELS

Normalized 1650 F, Tempered 1200 F

(normal expected values)

Composition** (%) C	Composition** (%) Ni	Tensile Strength (psi)	Yield Point (psi)	Elong. in 2 Inches (%)	Red. of Area (%)
0.25	2.00	93.500	57,200	26.4	53.6
0.26	2.11	94,000	56,000	25.5	48.8
0.27	1.98	95,000	58,500	26.0	49.0
0.28	2.10	96,000	61,000	26.5	51.6
0.29	2.04	100,000	60,750	25.5	49.5
0.30	2.15	103,000	62,500	25.0	50.0

**Manganese 0.85 to 1.00, Silicon 0.30 to 0.40, Phosphorus and Sulphur below 0.05.

Nickel-Manganese-Molybdenum Cast Steels: A composition often used in place of the 1.40 per cent nickel, 1.40 per cent manganese steel is that of 1.00 to 1.25 per cent manganese, about 1.25 per cent nickel and 0.10 to 0.15 per cent molybdenum. The molybdenum addition permits the use of higher tempering temperatures without adversely affecting tensile properties.

Nickel-Manganese-Copper Cast Steels: Studies indicate that the presence of copper improves the tensile and yield strength and the brinell hardness of these steels. Representative test values applying to steels of this group are listed in the table "Nickel-Manganese-Copper Cast Steels".

Nickel-Chromium Cast Steels: In addition to high strength, nickel-chromium cast steels have good elastic and ductility properties and offer good resistance to fatigue and abrasive wear. Normalized and tempered, they do not show markedly better mechanical properties than some of the less costly alloy steels. However, rapid quenching imparts improved hardness and strength, and these steels can be used advantageously for highly stressed parts the designs of which are sufficiently simple to permit liquid

quenching. Bulk of nickel-chromium steel castings is made with 0.30 to 0.40 per cent carbon, 1.00 to 1.50 per cent nickel, and 0.45 to 0.90 per cent chromium (approximately SAE 3135). Manganese usually varies between 0.60 and 1.00 per cent, silicon between 0.25 and 0.50 per cent, and in all cases phosphorus and sulphur will be under 0.05 per cent. Properties normally expected of these steels are listed in the tables "Nickel-Chromium Cast Steels".

In addition to the above there are nickel-chromium cast steels corresponding approximately to SAE 3240 and 3450, and these often are used for thick section castings that must withstand high stresses. Steels of the 2% nickel, 0.65% chromium type have long been used in cast steel valves for high-temperature service. They excel plain carbon cast steels at room temperature and, in addition, have better resistance to creep at 850 degrees Fahr. and higher.

Nickel-Chromium-Molybdenum Cast Steels: Addition of molybdenum to nickel-chromium steel, without reducing its mechanical properties or machinability, develops excellent air-hardening characteristics and makes the steel relatively immune to temper brittleness. In the air-hardened and tempered condition, physical properties often are equivalent to those obtained by liquid quenching many other cast steels. These steels are well adapted to large castings because of their deep hardening properties. Also, they retain high strength at elevated temperatures. Usual composition ranges (in percentages) are: C - 0.25 to 0.35, Mn - 0.60 to 0.80, Ni - 1.25 to 2.00, Cr - 0.60 to 1.00, and Mo - 0.30 to 0.40. Normal expected properties of various steels in this group are listed in the table "Nickel-Chromium-Molybdenum Cast Steels".

Nickel-Chromium-Manganese-Molybdenum Cast Steels: Generally these are produced in composition ranges of C - 0.30 to 0.40, Mn - 1.25 to 1.60, Ni - 1.00 to 1.30, Cr - 0.60 to 0.75, Mo - 0.30 to 0.40. Steels falling within this composition range, when normalized at 1650 degrees Fahr. and properly tempered have better all-around properties than the medium-manganese or nickel-chromium steels, superiority being greatest in yield and impact strength. They have exceptionally good air-hardening properties in that normalizing and tempering treatments develop properties equal to and in some instances superior to those obtained by the liquid quenching of various other steels. For comparable high hardness values they usually have greater toughness and ductility than the nickel-chromium steels. Steels of this type seldom are used in the liquid-quenched and tempered condition because practically the same properties can be obtained by the air-quench and temper treatment. Typical test values are listed in the table "Nickel-Chromium-Manganese-Molybdenum Cast Steels".

Nickel-Molybdenum Cast Steels: Molybdenum is added to nickel steels to improve their mechanical properties at normal and elevated temperatures. Also, the hardening capacity of nickel steels is greatly augmented by small quantities of molybdenum. Nickel-molybdenum steels in the carbon range of 0.20 to 0.40 per cent possess good

NICKEL MANGANESE CAST STEELS

Normalized 1550 F, Tempered 1200 F

(normal expected values)

Composition (%) C	Mn	Ni	Tensile Strength (psi)	Yield Point (psi)	Elong. in 2" (%)	Red. of Area (%)	Izod Impact (ft lbs)	Brinell Hardness No.
0.26	1.48	1.50	93,500	60,750	27.2	57.5	53	178
0.27	1.44	1.42	95,000	61,500	25.0	58.0	48	...
0.28	1.58	1.45	96,200	63,500	24.5	57.5	45	188
0.29	1.49	1.47	95,000	65,000	26.0	55.0	45	...
0.30	1.42	1.50	98,000	65,000	24.5	56.0	..	202
0.31	1.60	1.37	101,200	68,200	25.3	55.0	..	...
0.32	1.35	1.40	99,800	67,300	23.5	51.5	41	...
0.33	1.39	1.37	101,500	70,000	23.0	50.0	45	210
0.28	1.50	1.23	98,600	64,300	25.3	53.6	..	196

NICKEL-MANGANESE-COPPER CAST STEELS

Normalized and Tempered

(normal expected values)

Composition (%) C	Mn	Ni	Cu	Tensile Strength (psi)	Yield Point (psi)	Elong. in 2" (%)	Red. of Area (%)
0.27	1.02	1.47	0.42	86,000	56,000	23	34
0.31	1.15	1.80	0.62	92,000	55,000	23	36
0.33	1.02	1.15	0.49	89,000	54,000	25	40
0.36	0.81	1.60	0.76	92,000	56,000	22	37
0.26	1.03	1.47	0.63	90,000	55,000	23	34
0.36	1.03	1.73	0.21	96,000	59,000	25	41
0.36	1.18	1.37	0.80	94,000	51,000	23	36

ELEVATED-TEMPERATURE PROPERTIES OF FULL-ANNEALED NICKEL CAST STEEL

(C—0.35, Ni—3.00, Mn—0.82, Si—0.31)

Mechanical Properties	Temperature of Test 68 F	212 F	392 F	572 F	752 F	932 F
Tensile Strength (psi)	111,000	105,000	102,000	110,000	95,000	66,000
Elastic Limit (psi)	72,000	68,000	60,000	59,000	53,000	49,000
Elong. in 2 Inches (%)	13.0	13.5	12.0	11.7	15.0	17.5
Reduction of Area (%)	22.0	25.0	20.0	17.0	22.5	26.0

strength and ductility as well as excellent resistance to impact. The usual ranges in chemical composition (percentages) are: C - 0.20 to 0.40, Mn - 0.60 to 0.80, Ni - 1.25 to 2.00, and Mo - 0.25 to 0.40. Mechanical properties normally expected in steels of the above analysis range are shown in the table "Nickel-Molybdenum Cast Steels" and the values apply to steel in the normalized and tempered condition. Nickel-molybdenum steels of lower carbon content are used for castings requiring carburizing.

Nickel-Vanadium Cast Steels: These exhibit high tensile and yield strengths plus good ductility. Their general composition ranges (percentages) are: C - 0.26 to 0.35, Mn - 0.80 to 1.10, Si - 0.25 to 0.50, Ni - 1.35 to 1.80, V - 0.08 to 0.15. Normal expected properties of these steels, double normalized and tempered, are given in the table "Nickel-Vanadium Cast Steels".

APPLICATIONS

Nickel Cast Steels: Low-carbon, 2 per cent nickel cast steel has been applied successfully to the manufacture of locomotive frames, castings for mining, excavating and steel mill machinery, ship castings and other parts subjected to shock and fatigue stresses. Retention of impact resistance and ductility at low temperatures makes it well adapted to locomotive and miscellaneous machinery castings operated in cold climates. Medium-carbon, 2 per cent nickel steels have proved satisfactory for miscellaneous railroad castings, ship castings, large gears not subjected to severe abrasion, steel mill machinery, crusher frames, tractor and power-shovel frames, and similar parts requiring higher strength and elastic properties than those offered by the low-carbon, 2 per cent nickel cast steels.

Nickel-Manganese Cast Steels: These steels often are used to replace carbon and low-alloy steels when improvements desired in static and dynamic properties do not warrant the use of the higher alloy content steels. They see considerable usage in the structural members of freight cars, tractors, motor trucks, road building machinery, electrical machinery, etc.

Nickel-Chromium Cast Steels: Normalized and tempered nickel-chromium cast steels are used extensively for oil-well tools, sheaves, sprockets, tractor shoes, gears, cams and similar highly stressed castings. Quenched and tempered nickel-chromium cast steels containing C — 0.35 to 0.50, Mn — 0.60 to 0.80, Ni — 1.25 to 1.75, and Cr — 0.60 to 0.90 per cent, are used widely for hardened gears, cams, rollers, sprockets and various abrasion-resistant castings such as bucket teeth, small crusher jaws, and conveyor chain links. Those having percentages of C — 0.35 to 0.50, Mn — 0.50 to 0.75, Si — 0.30 to 0.37, Ni — 1.90 to 2.80, and Cr — 0.85 to 1.10 are, when properly heat treated, well suited for many highly stressed gears, pinions, rollers, etc.

Nickel - Chromium - Molybdenum Cast Steels: Recommended for castings requiring a combination of high strength, toughness, resistance to fatigue and abrasion. Typical applications include sprockets, gears, pinions, dredge parts, pulverizer hammers, crane wheels, impeller castings, roughing rolls, crusher heads, breaker plates, mill liners, oil field tongs and valves. Retention of hardness and strength at temperatures up to 1000 degrees Fahr. makes these steels useful for cement clinker chain, valves, fittings and other castings operating at moderately elevated temperatures. Also used extensively for abrasion resistant castings.

Nickel - Chromium - Manganese - Molybdenum Cast Steelings: These are applicable to the same service requirements as listed under the nickel-chromium-molybdenum series. Since they react so readily to air cooling, they can be subjected to high-temperature drawing treatments and retain considerable hardness. This enables strains to be removed from castings without sacrificing hardness to too great an extent, a quality required for abrasion-resistant applications.

Nickel-Molybdenum Cast Steels: Typical applications are heavy duty gears and large pinions, mining machinery castings, mill races, trip hammer dies, locomotive parts, tractor sprockets and tread plates or shoes, cargo hooks, etc. Because of their good air-hardening properties, these steels are adaptable to large or intricate castings where liquid quenching is not feasible. In the quenched and tempered state nickel-molybdenum cast steels are used as wearing parts which possess good ductility and impact resistance, an example of such service being the brake rim castings on oil well draw works.

Nickel-Vanadium Cast Steels: Miscellaneous medium and thick section castings for locomotives, rolling mill machinery, etc., also highly stressed gears and other parts for power shovels and other machinery subjected to rough service conditions. The favorable low-temperature properties permit its use in such services as railway equipment for northern climates and low temperature processes in the oil and general chemical industries.

FABRICATION

MACHINABILITY:

Extensive studies to date indicate that the machinability of alloy cast steels is similar to that of wrought steels of equivalent strength and ductility, like indentation hardness and similar microstructure. Machinability ratings are given in the table "Machinability Ratings of Annealed Hot Rolled SAE Steels" and ratings comparable to those listed may be expected of annealed cast steels. Often the skin on a steel casting contains bits of grit and sand which tend to wear cutting tools rapidly. This difficulty is circumvented, however, by making the initial cut on a casting a deep, or hogging cut. Generally, steel in the "as cast" condition is considered more difficult to machine than after it has been properly heat treated.

WELDABILITY§:

In general, alloy steel castings are welded by the same processes used for rolled alloy steel of the same composition. However, resistance welding is not used extensively because of the various forms and contours taken by castings.

Low-Carbon, 2% Nickel Steels: Are readily welded by the metallic arc and gas processes and sometimes may be welded in place without strain relief treatments as they possess no marked air hardening tendencies.

Nickel-Chromium Alloy Steels: These are not capable of being safely welded without preheating. For the lower tensile ranges having a maximum of 0.20 per cent carbon a preheat of from 200 to 300 degrees Fahr. is all that is necessary, but with the higher carbon contents that accompany the increased percentages of nickel and chromium, a 600 to 800-degree Fahr. preheat is considered desirable followed by slow cooling. For the highest carbon, nickel and chromium contents it is even desirable to raise the preheat temperature to from 900 to 1100 degrees Fahr.

(*Concluded on Page* 172)

§ From *ASM Metals Handbook*, 1939

MACHINABILITY RATINGS OF ANNEALED HOT-ROLLED SAE STEELS

SAE No.	Nominal Chemical Composition (%) C	Mn	Ni	Cr	Mo	Tensile Strength (psi)	Elastic Limit (psi)	Elong. in 2" (%)	Red. of Area (%)	Machinability Rating (%)*	Brinell Hardness
3340	0.40	0.45	3.50	1.50	....	110,000	90,000	22	58	42	218
2350	0.50	0.75	3.50	....	....	110,000	80,000	22	45	51	212
3250	0.50	0.45	1.75	1.07	....	108,000	80,000	22	50	46	215
3240	0.40	0.45	1.75	1.07	..	105,000	75,000	24	50	48	212
4340	0.40	0.65	1.75	0.65	0.35	100,000	80,000	25	60	58	230
3140	0.40	0.75	1.25	0.60	....	95,000	65,000	22	55	55	194
2340	0.40	0.75	3.50	....	....	95,000	68,000	25	58	54	200
3312	0.12	0.45	3.50	1.50	....	90,000	75,000	28	62	51	190
3230	0.30	0.45	1.75	1.07	....	90,000	65,000	25	54	52	210
3130	0.30	0.65	1.25	0.60	....	90,000	60,000	30	55	55	197
2330	0.30	0.65	3.50	....	....	85,000	62,000	26	58	60	177
3220	0.20	0.45	1.75	1.07	....	80,000	68,000	28	60	55	183
2515	0.15	0.45	5.25	....	....	80,000	65,000	32	70	47	165
2320	0.20	0.45	3.50	....	....	76,000	58,000	30	60	55	169
2315	0.15	0.45	3.50	....	....	74,000	55,000	32	62	60	160

*Machinability rating is given as a percentage of the machinability of cold-rolled SAE 1112.

NICKEL-CHROMIUM CAST STEELS (QUENCHED AND TEMPERED)

Air-cooled from 1650 F, tempered at 1250 F
(normal expected properties)

Composition (%) C	Ni	Cr	Tensile Strength (psi)	Yield Point (psi)	Elong. in 2" (%)	Red. of Area (%)	Brinell Hardness No.	Izod Impact (ft lbs)
0.30	1.27	0.65	99,000	57,500	23.2	45.5	206	44
0.31	1.40	0.75	99,600	58,000	22.5	44.3	212	41
0.32	1.33	0.79	100,000	60,000	22.5	43.0	208	39
0.33	1.47	0.82	100,000	63,000	22.0	43.0	212	41
0.34	1.41	0.73	99,800	64,250	21.2	41.2	215	37
0.35	1.38	0.86	102,200	66,200	21.0	40.7	218	38
0.36	1.51	0.75	104,000	65,900	22.0	40.3	215	34
0.37	1.36	0.91	104,000	65,800	20.0	39.0	220	32
0.38	1.28	0.88	104,000	66,500	18.5	34.5	217	30
0.39	1.43	0.85	108,000	68,200	19.0	35.0	228	30
0.40	1.40	0.87	106,700	68,000	19.5	34.8	230	26

NICKEL-CHROMIUM CAST STEELS (AIR-COOLED AND TEMPERED)

Water quenched from 1650 F, tempered 1250 F
(normal expected properties)

Composition (%) C	Ni	Cr	Tensile Strength (psi)	Yield Point (psi)	Elong. in 2" (%)	Red. of Area (%)	Brinell Hardness No.
0.30	1.78	0.69	106,500	84,400	23.0	46.5	229
0.35	1.89	0.89	111,300	88,300	20.0	44.1	...
0.40	1.55	0.75	114,300	94,750	19.2	40.3	...
0.45	1.36	0.68	118,300	100,250	18.5	38.5	260
0.20	2.67	1.12	100,700	72,450	22.6	46.6	...

NICKEL-CHROMIUM-MOLYBDENUM CAST STEELS

Normal expected values as water quenched and tempered, and normalized and tempered

Composition (%) C	Mn	Si	Ni	Cr	Mo	Water Quenched at 1650 F, Tempered at 1150 F: Tensile Strength (psi)	Yield Point (psi)	Elong. in 2" (%)	Red. of Area (%)	Normalized & Tempered 1150 F: Tensile Strength (psi)	Yield Point (psi)	Elong. in 2" (%)	Red. of Area (%)
0.44	0.67	0.21	1.39	0.60	0.22	154,750	139,000	11.0	28.0	124,250	92,000	16.0	35.5
0.35	0.86	0.30	1.39	0.68	0.25	148,500	135,500	12.0	31.0	118,500	90,000	17.0	40.0
*0.35	0.95	0.34	1.96	0.68	0.39	....	....	....	....	130,900	100,700	16.5	46.5
0.30	0.85	0.24	1.68	0.55	0.27	149,500	135,000	12.0	32.0	118,250	74,000	17.5	37.5
0.32	0.81	0.22	1.39	0.59	0.27	147,250	132,500	12.5	34.5	117,000	92,500	15.5	37.5
0.31	0.80	0.31	1.47	0.61	0.28	147,750	135,250	12.0	34.0	120,000	94,000	15.5	36.5
0.34	0.71	0.25	1.63	0.56	0.24	150,000	136,500	13.5	35.0	117,500	94,000	17.0	38.5
0.35	0.78	0.20	1.44	0.59	0.21	151,000	137,500	13.5	35.5	120,500	94,500	17.0	40.0
0.32	0.78	0.17	1.42	0.58	0.23	149,750	135,250	13.0	35.0	118,500	92,750	16.5	37.5
0.35	0.80	0.15	1.42	0.55	0.24	152,500	139,000	11.0	26.0	120,150	93,100	16.5	36.0

*Double Normalized.

HEAT TREATMENTS

Nickel Cast Steels: Most of these are double normalized and tempered.

Nickel-Manganese Cast Steels: Normalizing followed by tempering is the heat treatment usually specified.

Nickel-Manganese-Copper Cast Steels: Generally normalized and tempered.

Nickel-Chromium Cast Steels: Although these steels generally are normalized and tempered or double-normalized and tempered, for maximum hardness and strength they are water or oil-quenched and tempered.

Nickel-Chromium-Molybdenum Cast Steels: These may be normalized and tempered or liquid quenched and tempered, depending on the properties desired.

Nickel-Chromium-Manganese-Molybdenum Cast Steels: Since practically identical properties can be obtained in these steels by air-hardening and tempering as by liquid quenching and tempering, the latter heat treatment is seldom employed.

Nickel-Molybdenum Cast Steels: These generally are normalized and tempered. If they are not tempered following normalizing, they are apt to have poor impact and ductili Where carbon content is low they may be carburized.

Nickel-Vanadium Cast Steels: Usual heat treatment double normalizing, generally followed by tempering at te peratures near 1200 degrees Fahr. Single normalizing a tempering also is used. Mechanical properties do not diff greatly between these two types of heat treatment except th impact strength usually is considerably higher if the doub normalizing treatment is used. Higher strength can be o tained by oil and water quenching followed by temperin

RESISTANCE TO CORROSION

While the nickel in these steels does improve their co rosion resistance to some degree over that offered by carbo cast steels, they cannot, in the strict sense of the term, b classified as corrosion-resistant steels. Where these stee are used in severely corrosive conditions, they should b **protected by a suitable metallic or nonmetallic coating.** Oft a better solution is to employ one of the alloys that ha been developed specifically to resist corrosion.

NICKEL-MOLYBDENUM CAST STEELS

Normalized 1650 F, Tempered 1200 F

(normal expected properties)

Composition (%) C	Ni	Mo	Tensile Strength (psi)	Yield Point (psi)	Elong. in 2" (%)	Red. of Area (%)	Izod Impact (ft lbs)
0.20	1.35	0.29	86,000	57,200	27.8	54.6	..
0.22	1.46	0.30	87.500	58,000	25.0	48.6	56
0.24	1.88	0.36	89,500	63,000	26.5	48.0	60
0.26	1.65	0.40	91,000	63,000	24.4	51.7	52
0.29	1.82	0.35	92,250	65,200	22.6	47.0	..
0.30	1.50	0.30	90,000	60,000	22.0	45.0	50
0.32	1.38	0.31	90,750	60,500	23.8	50.2	..
0.33	1.34	0.33	91,200	61,000	24.0	52.0	..
0.35	1.75	0.30	100,000	70,000	23.0	50.0	44
0.40	1.82	0.28	111,000	82,500	18.0	40.0	..

NICKEL-VANADIUM CAST STEELS

Normalized 1700 to 1750 F, Normalized 1500 to 1550 F, Tempered 1200 F

(normal expected properties)

Composition (%) C	Ni	V	Tensile Strength (psi)	Yield Point (psi)	Elong. in 2" (%)	Red. of Area (%)	Izod Impact (ft lbs)
0.26	1.59	0.10	88,500	60,000	26.0	55.2	57
0.28	1.53	0.11	91,300	64,200	27.8	52.5	60
0.30	1.64	0.11	93,500	65,500	28.0	53.8	55
0.32	1.62	0.12	96,000	66.600	26.5	51.0	59
0.33	1.58	0.10	96,500	68,000	25.5	49.0	50
0.35	1.65	0.11	98,200	70,200	24.0	45.5	47

NICKEL-CHROMIUM-MANGANESE-MOLYBDENUM CAST STEELS

Normalized and Tempered

(typical test values)

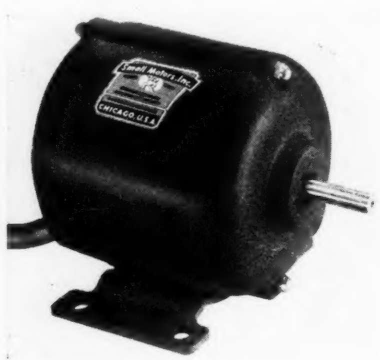
Composition (%) C	Ni	Cr	Mn	Mo	Heat Treatment* (deg F)	Tensile Strength (psi)	Yield Point (psi)	Elong. in 2" (%)	Red. of Area (%)	Bri Har No
0.34	1.22	0.71	1.58	0.32	1650 AC, 1250 T	125,000	92,000	22.7	51.2	..
0.35	1.50	0.90	1.25	0.30	1650 AC, 1100 T	138.000	118,900	16.0	45.0	302
0.33	1.15	0.60	1.35	0.35	1650 AC, 700 T	195,150	151,000	10.5	31.2	402
					1650 AC, 1000 T	167,650	130,850	14.2	34.9	37[illegible]
					1650 AC, 1250 T	118.200	88,150	21.8	49.4	25[illegible]
0.28	1.18	0.68	1.56	0.36	1650 AC, 1000 T	164,000	119,000	13.5	31.2	364
					1650 AC, 1250 T	119,000	89,000	22.2	51.6	25[illegible]
0.34	1.22	0.71	1.58	0.32	1650 AC, 1000 T	176,000	142.000	13.5	36.6	387
					1650 AC, 1250 T	124,000	92,000	22.7	51.2	269
0.42	1.26	0.60	1.48	0.39	1650 AC, 1000 T	177,000	146,000	14.5	36.2	40[illegible]
					1650 AC, 1250 T	119,000	91,000	19.5	42.7	269

*AC—Air cooled. T—Tempered.

NEW PARTS AND MATERIALS

Capacitor-Start Induction Motors

CAPACITOR-START induction motors have been announced by Small Motors Inc., 1308 Elston Ave., Chicago 22, together with a line of split-phase and shaded-pole types. They are wound for speeds of 3350, 1725 and 1150 rpm in capacitor and split-phase types or 3100 and 1550 rpm in shaded-pole types. Furnished with precision ball



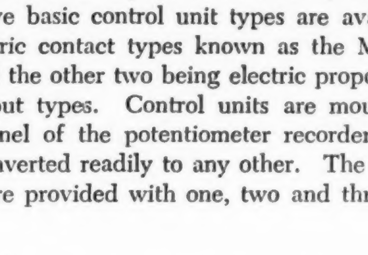
bearings, or oilless sleeve bearings, the motors have a high starting torque and a prompt reversal. They are built as ventilated models but may be obtained enclosed or explosionproof at a reduction in rating. Motors will operate vertically or in any mounting position when provided with proper thrust bearings. While the motors are regularly available with a cast iron housing, they are obtainable with aluminum or pressed metal housings. The motors are rated at 1/25 to 1/70 hp, and have overall dimensions of 3⅞ x 3⅞ x 4⅞ inches. Weight varies from 4½ to 7 lb, depending on the rating.

Nonflammable Thermosetting Plastic

FIRST OF THE new postwar products to be announced by The B. F. Goodrich Chemical Co., Rose Bldg., Cleveland is Kriston, one of a series of thermosetting resins, formed by polymerizing liquid monomer in the presence of a suitable catalyst. This nonflammable plastic with its optical and electrical properties has good resistance to abrasion and high resistance to oils and greases and most chemicals, including acids and alkalies. A somewhat viscous, water-clear, anhydrous liquid, having a specific gravity of 1.25 which can be cast in simple molds, Kriston sets to a hard, heat-resistant plastic. No water or other volatile products are released during polymerization, making easy the preparation of dense, nonporous articles. Shrinkage during polymerization is low. It has a refractive index of about 1.57, and can be made into a water-cle plastic or a wide range of colors which can be transpare translucent or opaque. In view of its high dielect strength and electrical resistivity, it has possibilities in th electrical field. Its refractive index and good physic properties make it a promising material for optical lense prisms, or transparent sheets. In the chemical and pr cessing industries the imperviousness of the material corrosive agents and solvents offers possibilities in fab cating parts for equipment such as valves, pumps, agitator controls, or for any equipment exposed to corrosive fume vapors and liquids.

Potentiometer Controller

NEW SERIES of electric-type potentiometer controlle has been introduced by The Bristol Co., Waterbury 9 Conn. Five basic control unit types are available, thr being electric contact types known as the Microact co trollers and the other two being electric proportioning an current input types. Control units are mounted on th internal panel of the potentiometer recorder. Any typ may be converted readily to any other. The three Micr act units are provided with one, two and three precisio

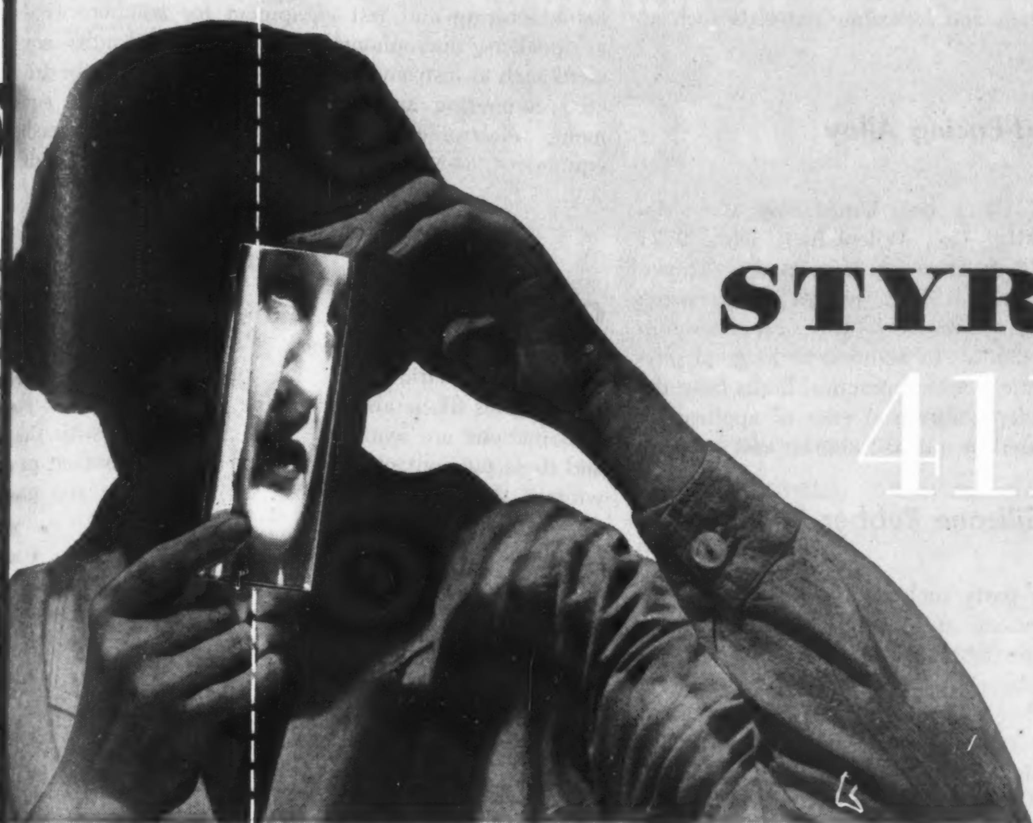


type toggle switches, respectively and six different te minal board construction arrangements to meet a wide a sortment of control circuit requirements. Proportioni controller may be used with any type of electric propo tioning valve and may be had with resetting contacts required.

Wrinkle Finishes Offered

FOR MATERIALS such as fabric, felt and other simil flexible materials, New Wrinkle Inc., Dayton, O., h introduced its synthetic rubber wrinkle finish. Availab in a wide range of patterns and colors, it does not requi

a new and still better polystyrene



STYRON

411

Finer Products—durable plastic products that are efficient, long lived and better appearing—these are the direct results of Styron 411C. Here is important news to every user of plastics. For this *new* member of a *new* polystyrene series produces improved finished products. Now beautiful surfaces are obtained—free from flow marks. High clarity and gloss are assured. And, of course, you still have all the familiar Styron advantages: sparkling colors, acid resistance, low moisture absorption, and outstanding dielectric qualities.

Faster Production—another advantage of Styron 411C. In actual use, this new Dow plastic speeds handling and improves molding. Reduced rejects and simple finishing operations produce greater yield per pound—greater economy for you.

Low Cost—a Styron advantage that continues unchanged—for Styron 411C is offered at the same low price. Write to the Plastics Sales Division or any sales office for complete details.

let's work it out together

Success in plastics is not a one-man nor even a one-industry job. It calls for the cooperation and combined skill of manufacturer or designer plus fabricator plus raw materials producer. Working together, this team saves time and money and puts plastics to work successfully. Call us—we'll do our part.

PRESENT AND POTENTIAL USES: Lighting fixtures; insulators; battery cases; hydrometers; funnels; closures, food handling equipment; pharmaceutical, cosmetic and jewelry containers; costume jewelry; novelties; refrigeration parts; pens; pencils; liquor dispensers; escutcheons; chemical apparatus; lenses; decorative objects, trim.

PROPERTIES AND ADVANTAGES: Clear, translucent or opaque; broad color range; excellent high frequency electrical insulator; can "pipe" light through rod at angles, and around corners; resistant to acids and many alkalies; low water absorption; light weight; stable at low temperatures.

THE DOW CHEMICAL COMPANY, MIDLAND, MICHIGAN

New York • Boston • Philadelphia • Washington • Cleveland • Detroit • Chicago • St. Louis
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DOW

PLASTICS

STYRON • STYRALOY • ETHOCEL
ETHOCEL SHEETING • SARAN • SARAN FILM

cooking. Another finish—a resin emulsion base wrinkle composition—has been brought out by the company. This finish also requires no cooking and is produced in a wide variety of wrinkle textures and patterns. It is applicable to both flexible materials and inflexible materials such as metal.

Hard-Facing Alloy

ANNOUNCEMENT OF a new hard-facing alloy, developed by Eaton Mfg. Co., Wilcox-Rich Div., 9771 French Rd., Detroit 13, has recently been made. Known as Eatonite, this material is heat, corrosion and wear-resistant and is readily applicable to valve faces by conventional welding methods. In addition to its good physical properties, Eatonite is within practical limits from the standpoint of cost, adaptability and ease of application. It has already been used in military aircraft and vehicles.

Molded Silicone Rubber Parts

M OLDED Silastic parts such as gaskets, seals, hose, rubber to metal adhesion and miscellaneous parts, are now available for the first time commercially through Connecticut Hard Rubber Co., 407 East St., New Haven 9, Conn. Developed by Dow Corning Corp. from sand, this new high-temperature elastic material withstands temperatures from minus 70 F to plus 500 F, and retains its original resilience and flexibilty. Its good dielectric properties—arc, corona and oxidation resistance—assure durability under hot service conditions. The new silicone rubber offers many prospects for designers, but parts must be engineered and frequently reinforced with glass.

Nonflammable Gasket Sealer

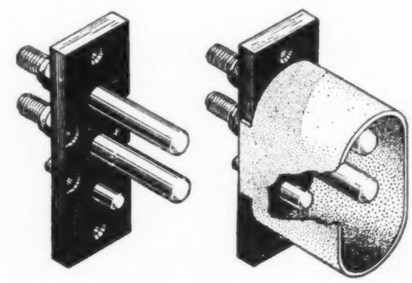
D ESCRIBED AS nonsettling and nonhardening, Sumtex MM-50 sealer is unaffected by oils and acids, and soluble in carbon tetrachloride. Tests up to 350 F and in high-pressure hydraulic systems have shown no effect on the essential characteristics of the material, according to the company. This nonflammable gasket sealer is manufactured by Summit Paint & Varnish Co., 581-89 Windsor St., Hartford, Conn.

Nonlinear Potentiometer

DEVELOPMENT of a nonlinear, wire-wound potentiometer has been announced by The Fairchild Camera & Instrument Corp., New York. The instrument is claimed to have a high degree of accuracy which depends on the shape of the desired curve of resistance versus rotation, but the maximum actual error in reproducing the desired curve is less on each particular job. Tolerances of one-half per cent or better have been consistently reached for certain curves. At present the company is producing one standard size, with a 1⅞-in. outside diameter, in quantities, and plans additional sizes. The model now being manufactured can be used singly or stacked; it has been banked to 18 on one shaft. Linear u are also available. Uses of the nonlinear potentiomet include computing gunsights and bombsights, radar na gational and aiming equipment, aircraft engine contr manufacturing and test equipment for components su as speakers, microphones, etc.; industrial control equi ment such as instruments for process control, motor drive etc.; computing and analyzing instruments and equi ment; electronic heating equipment, electro-medic equipment, and communication equipment of all kinds.

3-Contact Battery Receptacle

O RIGINALLY DEVELOPED for aircraft starting equi ment, the new three-contact battery receptacle introduc by Cannon Electric Development Co., 3209 Humboldt S Los Angeles 31, is also adaptable to industrial uses. Fo combinations are available: Complete fitting with shie and three pin contacts; shield less small pin contact; pa without shield but having small pin contact; and pa



without small pin contact. Contacts are brass with silv plate finish, and meet AN capacity requirements; o negative, one positive. Large contacts are 7/16-inch i diameter, small contact 5/16-inch in diameter for indicat light. Receptacle panel is phenolic; drilled for two moun ing holes. The shield is die-cast aluminum alloy with sa blast and clear lacquer finish and is fastened by four eyel to panel.

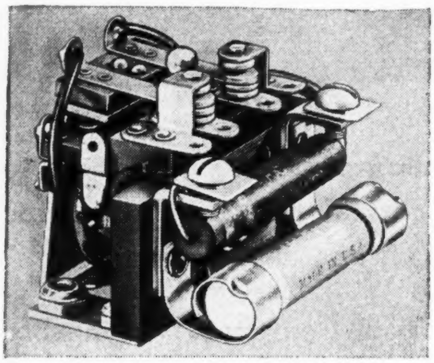
High-Capacity Blowers

DELIVERING 8000 cfm and 10 in. sp, turning at 34 rpm, the new blower of Buffalo Turbine Corp., 21 Buffalo 11, has wide application in many fields. Su applications include heating, ventilating and air cond tioning, dust removal, conveying and processing, co ovens and blast furnaces. The new blower is driven b an 8-in. diam, 20-hp motor. Weight of the complete u is 130 pounds. The company's line is to include a wi range of direct motor-driven units with air pressures fro ⅜-in. to 100 in. of water at synchronous motor speed and also direct-connected turbine-driven units up to 1 psi and 100,000 cfm.

Flasher-Interrupter

APPLICATIONS of the new flasher-interrupter a nounced by Electronic Testing Laboratories, 44 Summ Ave., Newark 4, N. J., include aircraft identification lig

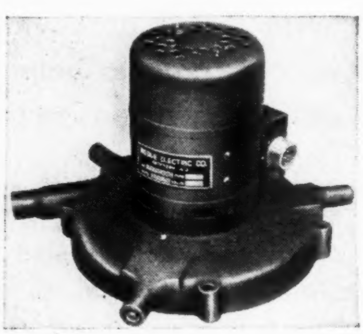
ing, control circuit as well as marine, industrial, automotive and railway signalling devices. It can be used wherever a predetermined number of interruptions are desired in any electrical or electronic circuit. Comprising a miniature timing device and a noninductive resistor unit, the flasher-interrupter is normally furnished in an open design, but any required enclosure can be supplied including hermetically sealed or pressurized types. All components are incorporated in a single assembly which is compact and lightweight (only 7 ounces). Four studs are provided for mounting with elastic stop units, eliminating shock and vibration. It is designed to withstand 10g's in



aircraft applications. Interruptions can be controlled through a range of from 60 to 80 per minute by varying the current through the thermal unit. Operating voltages include all standard alternating and direct-current ranges and frequencies, while other voltages and frequencies can be supplied on special orders. Normal actuating current is approximately 200 milliamperes. Contact ratings are 15 and 25 amp, 115 volts alternating current (noninductive).

Lightweight Fan Motor

AN ULTRA LIGHTWEIGHT fan motor has been designed by Bogue Electric Co., 40 Kentucky Ave., Paterson 3, N. J., for use with high-capacity blowers. Simple in construction, the motor is clean-cut and modern in appear-



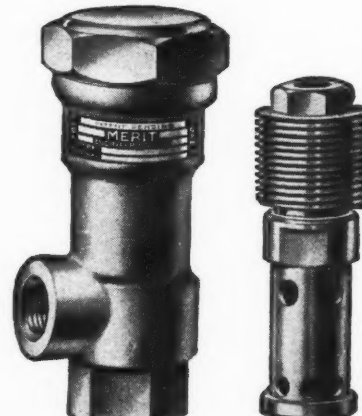
ance, and has sealed bearings requiring negligible servicing. It is designed for 24 volt operation on direct current, but can be adapted for any specified voltages, and delivers 2 hp. Self-ventilated, it will operate continually in any position in high ambient temperatures. Windings are specially designed to match fan characteristics and spe of 5000 rpm or higher are recommended. By mounti the motor directly on the blower housing, one end shie is entirely eliminated.

Synthetic Plastic Adhesive

SYNTHETIC PLASTIC adhesive for sandwich co struction, designated as Cordo-Bond No. 250, has bee announced by Cordo Chemical Corp., 34 Smith St., No walk, Conn., to provide laminations of metals, plastic and woods in various combinations. It bonds quickly b baking at a glue-line temperature of 250 F under a pre sure of 50 psi. Bonds show high resistance to water, mil acids, alkalis, oil, saltspray, and general weathering co ditions. Having a sheer strength up to 2000 psi, the ma terial is suitable for light-weight, high-strength sandwic construction, and other mass production bonding of mo materials in common usage.

Hydraulic Relief Valve

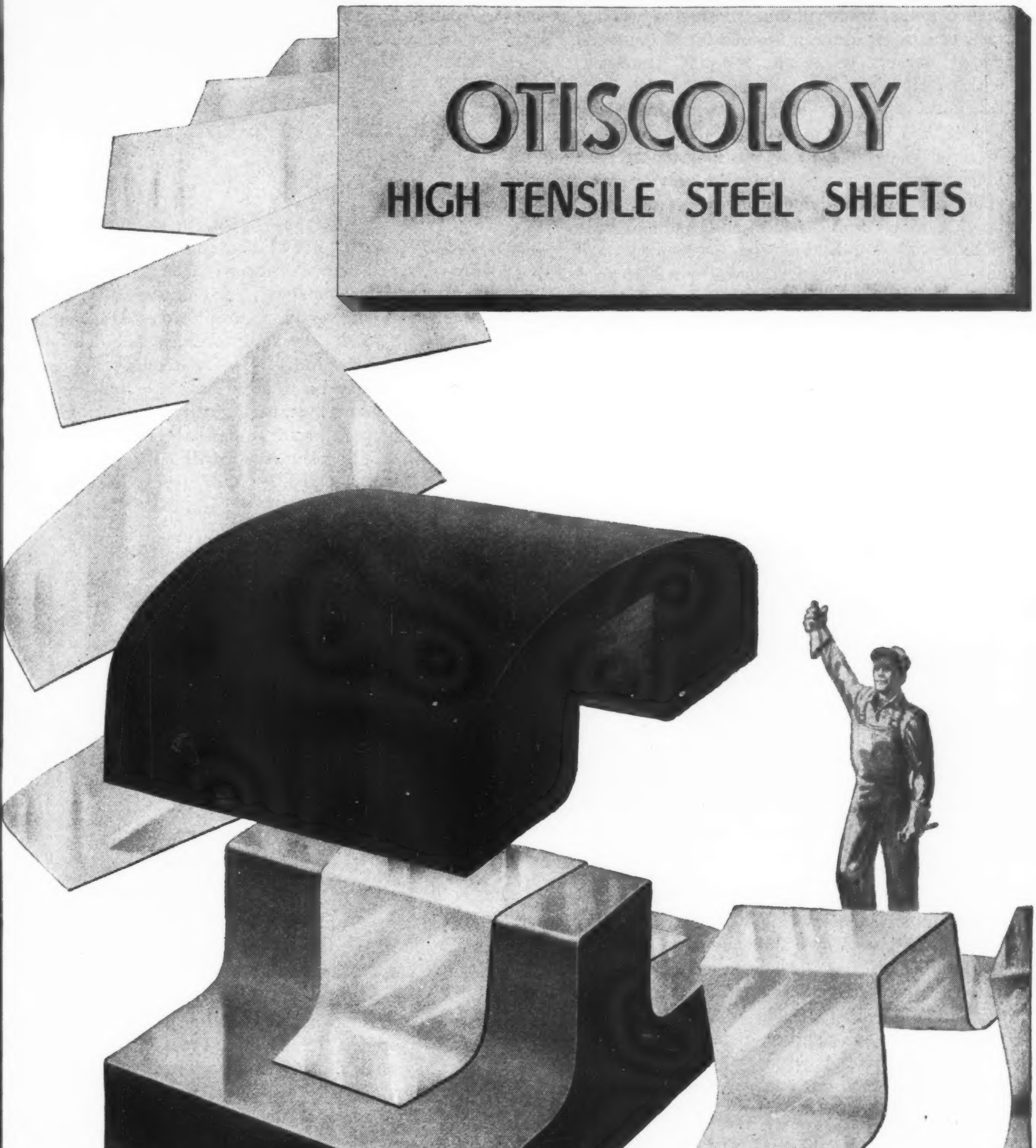
SIMPLIFIED DESIGN of the new hydraulic relie valve, announced by Merit Engineering Inc., Providence R.I., provides interchangeable cartridges for both aircraf and industrial housings. Two valves, with various sets o springs, cover a controlled pressure range of 0.75 to 300 psi with flow from zero to 160 gpm. Design of valves i such that precision operation and positive control can b



maintained within the foregoing limits. The cartridg may be obtained separately as a component for buildin into machine tools, pumps and other equipment where hydraulic relief valve is required. This special design en sures smooth operation free from chatter and with n "wire drawing".

Heat-Resistant Facing Alloy

MADE IN RODS, bars and inserts, Callinite alloys o Callite Tungsten Corp., Union City, N. J., are produce by the powder metallurgical processes. This high con ductivity facing material is used for applications requiri



J&L STEEL

A high strength steel that is easily fabricated and readily welded. May be hot or cold formed. Affords reductions in weight . . . its greater strength permits use of lighter gauges. Resists corrosion. Otiscoloy available in both sheets and plates for a wide variety of applications.

JONES & LAUGHLIN STEEL CORPORATION
PITTSBURGH 30, PENNSYLVANIA

high currents, where pitting, sticking or welding of contacts occurs. It also can be used for facing arcing tips on circuit breakers, relays, etc. Type TC (tungsten copper) withstands severe electrical erosion and mechanical wear through the stability of tungsten at high temperatures and its arc resistance qualities. This type is available in three grades. Type ST, a tungsten-silver alloy, has higher conductivity and is suited to heavy current-carrying applications where lighter contact pressures are encountered. This type also is furnished in three grades. These Callinite alloys are produced in standard and special shapes. Rods can be furnished from 3/16 to 1 inch in increasing diameters of sixteenth inches. Lengths vary up to 8 inches. Bars, rectangular and square, are made in widths from 1/2 to 1 3/8 inches. Lengths range up to 8 inches. Inserts are available from 3/16 to 2 inches in diameter, with heights from ⅛ to 1 inch.

Silicone Rubbers

FILLING THE need for rubbery materials combining heat resistance with elasticity and compressibility, a new silicon rubber, Silastic, is being produced by Dow Corning Corp., Midland, Mich., in various stocks for molding, extruding, coating and laminating. Because of its inorganic origin, the material remains elastic after heating at temperatures up to 500 F and retains flexibility at temperatures as low as −70 F. Stocks are available for molding flat sheets, gaskets and other shapes. Silastic-coated lead wire and other continuous extruded shapes are made from stocks designed for extruding. Also available are stocks compounded for coating glass or asbestos cloth to produce flexible, waterproof, heat-stable, oil-resistant gaskets, diaphragms, tape and electrical insulation which is noncracking, arc and oxidation-resistant. It is used also to insulate wire-wound resistors with waterproof, heat-resistant, elastic coatings able to withstand severe and repeated thermal shocks. Silastic adheres to glass, vitreous enamel, iron, steel and aluminum, constituting a protective coating which is resistant to oil and salt brines at elevated temperatures. Some additional properties include tensile strength of from 200 to 300 psi, elongation ranging from 70 to 115 per cent, dielectric constant of 5 to 7.5 at 1,000,000 cycles, power factor of .13 to .18 at 1,000,000 cycles, and dielectric strength of 500 volts per mil.

Shielded-Arc Electrode

FOR GROOVE BUTT joints and welding horizontal or flat fillets in the higher tensile steels such as ASTM A-212, a new shielded arc electrode has been offered by The Lincoln Electric Co., Cleveland 1. According to tests, groove butt joints made with the new electrode, Fleetweld 11-HT, are good and free of porosity. Fillet welds are smooth, with a flat face. Having a low spatter loss, the electrode welds are produced with a steady arc and are free from undercut. Speeds are good, and low-alloy, high-tensile steels can be welded easily and rapidly with the new electrode. It may be used either with alternating or direct current, and if direct current is used, the electrode should be negative. Conforming to American Welding Society specifications E-7020 and/or E-7030, is available in 3/16 and 1/4-inch diameter sizes, 18 inches long, in standard containers of 50 pounds each.

Engineering Dept. Equipment

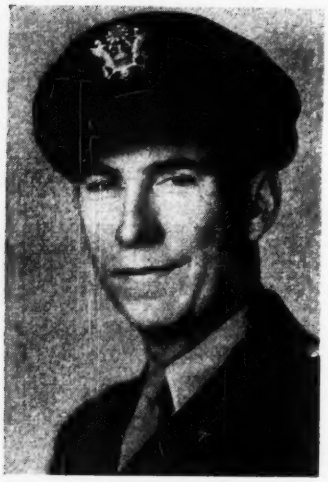
42-in. Continuous Printer

FOR MAKING actual size copies of written, printed, drawn, typed or photographed material by the hundreds, a new 42-in. continuous printer has been introduced by American Photocopy Equipment Co., 2849 North Clark Ave., Chicago 14. Available for immediate delivery, without priority, the Model CP-421 requires no darkroom. Photocopies may be made in ordinary subdued lighting. The printer has proved itself particularly suitable for making photographic tracings from large blueprints inasmuch as it will handle photocopy paper up to 42 in. in width of any length. Operation is simple: Original, together

with photocopy paper, is placed on the endless belt which takes it through the machine, exposes it, and deposits it on a tray ready for processing. Belt moves at speeds from 1 to 20 fpm, which provides proper exposure as speed may be varied by turning small knob. Shutter opening can also be adjusted. Light is obtained from two 40-watt 48-in. fluorescent lights—one in amber for making negatives, the other in white for making positives. Each light is controlled by its own switch.

Heavy-Pressure Pencil

COLORED INDELIBLE pencils, manufactured by Reliance Pencil Co., Mount Vernon, N. Y., stand up under more than average pressure. Aimed to meet the requirements of the "heavy-pressure" writer, the pencil absorbs an unusual amount of strain, sharpens to a fine point, holds the point for a long time, and retains smooth, easy-flow writing quality. A selection of colors for every type of need is available.



Col. T. B. Holliday

W. S. Winfield

Ralph E. Middleton

MEN... of machines

COL. T. B. HOLLIDAY, well-known Air Force engineer "who made electricity the slave of the airplane," recently has been appointed chief of the Engineering Division's equipment laboratory, according to an announcement at headquarters of the Air Technical Service Command. This appointment climaxes a 16-year career as an equipment laboratory engineer. Colonel Holliday is credited with having established specifications by which weight of motors, generators, and wire was reduced, making possible the operation of generators at high altitude. The number of electric motors in a pursuit plane was increased from one to eleven while more than 140 were installed in the big bombers. Output of generators was increased by 1600 per cent, giving the B-29 enough power to take care of household and industrial electrical needs of 500 people. Colonel Holliday again demonstrated his engineering ability in a new, much larger airplane, by guiding the development that gives the plane twice the electrical power of the B-29 while reducing weight of motors by one fifth, compared with the B-29. In addition, the new design saves more than a ton of wire. As a further indication of his ability, Colonel Holliday announced that electric motors, powered from gas turbines, could whirl propellers to provide better aerodynamic design.

W. S. WINFIELD, the new chief engineer of the home radio division of Westinghouse Electric Corp., has been closely identified with the radio and television industry since 1929, and has made several important contributions to basic receiver circuit development and design. Mr. Winfield formerly had been connected for eight years with Colonial Radio, Buffalo, N. Y. During this time he pe[rfected] a low-noise converter system a[nd] other electronic innovations used in w[ar]time communications equipment. In a[d]dition, during 1942-43, he served [as] consulting engineer to the Ordnance D[i]vision of Bell Aircraft, specializing [in] electronic devices. Mr. Winfield start[ed] his career as traffic engineer for the F[t.] Wayne Telephone Co., in 1928. Betwe[en] 1929 and 1933 he held a number [of] radio engineering posts including th[at] of development engineer for the Stei[n] Radio Corp., chief engineer for [ ] Super Products Corp., and engineer [in] charge of shortwave development [for] the Transformer Corp., of America. [A] native of Ft. Wayne, Mr. Winfield is [an] electrical engineering graduate of Pur[due] university.

RALPH EDGAR MIDDLETON, c[on]nected with the Aireon Mfg. Corp., si[nce] 1941, has been elected vice president [in] charge of engineering of the hydrau[lic] division. Born in Michigan, he spent [ ] years in the College of Aeronauti[cal]

gineering at the University of Michigan. He graduated in 1929 with a degree of Bachelor of Science in aeronautical engineering, having gained valuable extra-curriculum experience in wind tunnel, stress analysis and detail design of aircraft. After graduation he joined the Army Air Forces at Wright Field, Dayton, as junior aeronautical engineer, devoting his time particularly to aerodynamics. It was during these years that he became involved in a development of hydraulic shock absorbers, from which followed the first accurate method of drop testing and analyzing performances of hydraulic shock absorbers for aircraft. He soon became chief engineer for this type of work at Wright Field, where eventual expansion finally included development of hydraulic systems and retractable landing gear problems for aircraft in general, resulting in special photographic recording apparatus for drop testing gear, development of special high speed pressure recording devices, and other types of laboratory equipment for research work on hydraulic systems. Prior to becoming associated with Aireon, he was connected with the Curtiss Wright Corp. as staff engineer on landing gear design. While there he designed the landing gear and tail wheel installations for the Curtiss Wright C-46 and for three other models.

•

ALBERT F. WAKEFIELD, president of the F. W. Wakefield Brass Co., Vermilion, O., is the new president of the Illuminating Engineering Society.

•

BERTON H. DELONG in his new post as director of Carpenter Steel Co. will continue to supervise the research and development work of the company. Mr. DeLong has been with the company since 1910.

•

DR. WILLIAM E. WICKENDEN was recently elected president of the American Institute of Electrical Engineers for the year beginning August 1, 1945. Dr. Wickenden is president of the Case School of Applied Science, Cleveland.

•

FOSTER R. WOODWARD, who recently had been associated with Westinghouse as welding engineer, has joined the staff of Progressive Welder Co. as welding applications engineer.

•

C. H. REYNOLDS has been chosen by the War Department as a member of a group of American business men who are inspecting industrial plants in Germany and other European countries. Mr. Reynolds, who has a broad knowledge of engineering and manufacturing processes, is vice president of The Sheffield Corp., Dayton, O.

•

HOWARD A. DARRIN, well-known automotive stylist and engineer, recently joined the staff of Graham-Paige Motors Corp., Detroit 32, and will play a major part in the designing of the company's postwar automobiles.

•

J. F. CAMPBELL has been appointed chief development engineer, and R. W. PHILLIPS, laboratory director, of The Weatherhead Co., Cleveland. Mr. Campbell was previously director and chief engineer of the fuel injection division, Holley Carburetor Co. In his new position he will cond the company's development program, with the assistance RALPH ERSKINE, formerly of the development engineeri staff, who was named assistant development engineer.

•

WILLIAM J. PERFIELD as chief engineer of the mechan cal division of Lear Inc., will have complete charge of engineering activities of this division.

•

DR. O. S. DUFFENDECK has been appointed vice pres dent and director of research and engineering, Nor American Phillips Co. Inc. He formerly had been direct of research.

•

GEORGE S. GARRARD has been named chief engineer Briggs Clarifier Co. He had been assistant chief engineer charge of all engineering branches for Jacobs Aircra Engine Co.

•

W. SPRARAGEN, present executive secretary of th Welding Research Council of the Engineering Foundatio has been promoted to the newly created position of d rector.

•

A. M. WIGGINS, who has an invaluable background in th design of microphones and acoustic devices, has been a pointed chief research engineer at the Electro-Voice Corp South Bend, Ind.

•

JOHN W. CRAIG, who for the past four years has bee devoting most of his efforts to the development and im provement of the Mark 14 antiaircraft gunsight built b Crosley Corp., has been appointed general works manag of the Richmond, Ind. plant. Mr. Craig is well equippe to take over the active supervision of the plant in whic electric refrigerator and home freezer production will b under way.

•

WILLIAM R. HOUGH, formerly product development e gineer, has succeeded FRED E. HARRELL as chief engine of Reliance Electric & Engineering Co., Cleveland. M Harrell becomes general works manager.

•

LEWIS M. CLEMENT has been made vice president charge of research and engineering of the Crosley Corp Cincinnati 25, following transfer of control of the compa to The Aviation Corp.

•

HOWARD F. DOLL as the new chief engineer will pl an important part in developing postwar plans for Vic Electric Products Inc.

•

ROBERT J. WOODS, noted aircraft designer, has been a pointed special technical adviser to LAWRENCE D. BEL president of Bell Aircraft Corp., Buffalo. In addition new duties concerning future aircraft developme and production at Bell, Mr. Woods will also direct oper tions of the corporate Product Planning Group, a resear organization set up several months ago to investigate ne products in the aviation field.

Designing Computing Mechanisms

(Concluded from Page 128)

giving the polar co-ordinates for every point on the driving wheel's periphery. In like manner:

$$r_2 = \frac{C\dfrac{dx}{dy}}{1+\dfrac{dx}{dy}}$$

which, when dx/dy is expressed as a function of y, gives the polar co-ordinates of every point on the periphery of the driven wheel.

Scale of the tapewheel is limited by the fact that neither wheel can revolve more than one revolution, usually considerably less. Further, the range of the function is limited to the region where dy/dx is finite. The latter limitation can sometimes be circumvented by various mathematical expedients, such as adding a straight line to the function and taking it out again after computation by means of a differential connected to the input.

Tape wheels need not be in contact, but the shapes of the two wheels then are no longer determined solely by the function. The shape of one wheel becomes arbitrary; it could, for example, be circular. Shape of the other wheel then is fixed by the shape chosen for the first wheel and the nature of the function to be computed.

NONCIRCULAR GEARS: These devices, also appropriately called "queer gears", are identical in principle with tape wheels, except that the pitch surfaces are kept in rolling contact by gear teeth instead of crossed tapes. The outlines of the pitch surfaces are computed as described in the foregoing for tape wheels, while the outlines of the blanks are parallel curves separated from the pitch curves by the amount of the addendum.

Cutting the Teeth of Noncircular Gears

Design of the blanks is fairly simple, but cutting the teeth themselves is another story. As is well known, the shapes of gear teeth vary with the radius of the gear, while in this gear the radius of curvature of the pitch line is continually changing. The correct form of teeth would be generated by rolling the pitch line against that of a standard gear or rack, as is done in a gear generator. However, the ordinary form of gear generator cannot be used, because of constantly changing center distance and ratio.

One solution is to cut the teeth on the 14½° composite system, using formed milling cutters. To do this a table should be prepared showing the radius of curvature of the pitch surface and the co-ordinates of the center of curvature for each point where a tooth space is to be cut. A milling machine provided with a cross-feed micro[meter] should be used so that, as the gear is indexed for e[ach] tooth, it can be fed over according to the table, in o[rder] to bring the cutter down normal to the pitch curve. T[he] cutter is chosen to suit the radius of curvature at the t[ooth] space being cut. Usually one cutter will accommod[ate] several teeth. A reference hole should be drilled in [the] blank prior to cutting to establish a calibration point [for] the first tooth space. The two gears must also be ma[ted,] i.e., a tooth space must be located at a definite spot on [the] driver to line up with a tooth at a corresponding spot on [the] follower. This system, while not perfect, should produ[ce] gears equal to any cut by the formed mill process. So[me] improvement can be obtained by cutting them slig[htly] oversize, and then lapping them in by pairs.

BARR AND STROUD DEVICE[6]: This device, *Fig.* 35, rep[re]sents the ultimate development of the queer-g[ear] idea. To enable the gears to make more than one revo[lu]tion, the teeth are placed in helicoidal surfaces inst[ead] of in planes. Since the successive turns of the two g[ears] would interfere, transmission from driving gear to driv[en] is made through an idler pinion. The driver and follow[er] are both mounted on stationary screws having the sa[me] lead as the helicoids on which the teeth are placed. Th[us] the points of engagement with the idler maintain a fi[xed] axial position as the gears revolve. Provision is made for [the] idler to move sideways as the radius of one gear i[n]creases and the other increases.

Tape Wheels Can Use Helicoidal Surfaces

Tape wheels also can be constructed on the princi[ple] of the Barr and Stroud device, paying off the tape fr[om] one spiral and picking it up on the other, but means m[ust] be provided to keep the tape under tension regardless [of] the direction of rotation. A torsion spring on the output w[ill] serve in many cases.

COMPUTING DATA FOR TABULAR MECHANISM: T[he] reader by now has become aware that one of the great[est] chores in the design of these devices is the vast amou[nt] of computing which must be done to tabulate the manu[]facturing data. Since this often involves handling high[ly] complicated expressions, any methods which will short[en] this labor are most welcome. Free use should be made [of] the various interpolation formulas employing higher d[if]ferences[7]. These formulas are generally simplest when i[n]terpolating to the mean, so the interval between accurate[ly] computed tabular entries should always be lengthened b[y] multiples of 2 (2, 4, 8, 16, etc.). Also if a calculati[ng] machine is used, it will be found much easier to arran[ge] the formulas so that the tabular values are used, rath[er] than the actual differences. The writer has found that t[he] least work is involved in most cases if the interval [is] chosen so that a formula requiring four tabular valu[es] will give accurate results (Bessel's central-difference fo[r]mula).

LINKWORK MECHANISMS: Four-bar linkages hav[ing] cranks and connecting links of unequal length have be[en] utilized for computing functions. By properly choosing th[e] relative lengths and compounding the mechanisms, [al]most any function can be approximated[8].

In Part III of this series, to be published next mo[nth,] mechanisms for performing integration will be discu[ssed.]

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[6] U. S. Patent 1,159,463.

[7] The book mentioned in footnote 4 contains a good exposition of interpolation.

[8] Unpublished manuscript by Antonin Svoboda, Radiation Laboratory, Massachusetts Institute of Technology. A book on linkwork mechanisms by Dr. Svoboda will be published shortly.


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Nonferrous Metals

(Continued from Page 132)

be more than doubled, tensile strength slightly increased, and elongation and hardness simultaneously increased by improved proportioning of gates, vents, and overflow wells; the gain being due entirely to the production of sounder castings. Casting pressures which formerly ranged from 400 to 2000 psi, depending upon alloy and size of casting, have recently been run up to as much as 15,000 to 25,000 psi for aluminum or magnesium alloys and small pieces, *Fig.* 4. Due to machine limitations, the tendency is to use lower unit pressures for larger castings of the light-metal alloys.

Extended aging tests, ranging up to seven years, which were made on some of the commonly used zinc-base alloys show that they tend to lose a small proportion of their tensile strength but to gain in ductility after several years at room temperatures. The introduction of lead-base casting alloys was a wartime development to relieve shortages of other metals. These alloys do not equal the strength and hardness characteristics of the zinc-base and aluminum-base alloys but some have been developed which are inexpensive and sufficiently hard for certain uses. Lead-alloy casting metals are now available which will show tensile strengths up to 11,000 psi and brinell hardness up to 22. During the wartime shortage of other metals, some of these were used for such purposes as small V-belt pulleys, parts, fittings, etc.

Silver Bearings

Result of work at Battelle Memorial Institute, an alloy was produced containing 2½ to 5 per cent silver, 10 to 15 per cent antimony, 2 to 5 per cent tin, with the balance lead. The silver content provided the same temperature-hardness relations as were found in the prewar tin babbitts, while the small tin content provided corrosion resistance.

This alloy has greater strength, ductility, and bendability than the lead babbitts; it also possesses greater resistance to squeezing out at elevated temperatures, which permits its use in applications where the lead babbitts could not be employed, *Fig.* 5. Tests on bearings run dry indicated that the tin-base babbitts might run slightly longer than the silver-lead babbitts but that the latter were equal in every other respect. Because of the small amounts of silver required, this new babbitt material can be produced for less than the cost of tin babbitts. Based on 1941 prices of the metals, the tin babbitts cost around 45 to 50 cents per pound, which compares with 21 cents for an alloy containing 2.6 per cent silver, and 33 cents per pound for an alloy containing 5 per cent silver.

Laminated Metals

The laminated metals may be divided into three groups: (a) Those metals which are surfaced with other metals for protection against corrosion, (b) those metals which are laminated for the purpose of producing thermostatic response, and (c) those laminated for electrical applications. Prior to the period covered by this article, the Lukens Steel Co. started production of sheet steel, ranging from 3/ in. up to heavy plate, faced with nickel, monel, inco stainless steel, and silver. The rolling of high-stre aluminum alloys with a surfacing of commercially p aluminum to increase their corrosion resistance has been in vogue for so many years that it does not warr more than mention here.

This practice has recently been extended to some o combinations. One is "Armco aluminized steel", which c sists of soft steel sheet (either regular low-carbon or " pel steel") upon which a surface layer of essentially p aluminum is obtained by a hot-dip method. The streng and low cost of steel is thus combined with the spe advantage of aluminum. This combination also seems have good resistance to corrosion at high temperat It will withstand up to 900 F, without discoloration even where it finally discolors, it will not scale at te peratures well above 1000 F. It is now being used s cessfully for such applications as mufflers of internal-co bustion engines. The advantages in other cases will more obvious since aluminum shows good corrosion sistance to many acids and other corrosive liquids. T high reflecting power of aluminum for light and hea also utilized in some applications of this metal. The a herence of the two metals is excellent and sufficient permit even moderate forming and drawing without d stroying the surface or causing separation of surface ma rial from base. The aluminum-coated steel can be weld successfully, provided appropriate technique is used.

Another application of laminated metals is used by so makers of bronze bearings in producing steel-back bronze-and-graphite-faced bearings. Bronze bar is po dered, mixed with graphite, sintered, and applied to steel base to form a flat laminated sheet which is then and formed into bearing bushings.

Another laminated-metals development of the past years is a clad steel sheet or strip, marketed under tradename of "SuVeneer". This development was spired chiefly by the wartime shortage of copper, and need for conservation of this metal. Its first applicati was the coating of steel sheet with a thin layer of hig copper brass for drawing into small-arms bullet jacke The Superior Steel Corp., as a result of its experience w this clad steel for bullets, is now marketing a variety clad metals, including steel clad on one or both sides wi copper, several types of brasses and bronzes, nickel, mon and several types of stainless steels. This material available with certain combinations of facing materia one on one side and a different one on the other in equ or unequal thicknesses. The bond between the faci metals is mechanically inseparable. Thus, if the core soft steel, the laminated sheet or strip can be formed an deep drawn with no risk of separation. If the core is high-carbon steel, the material can be heat treated an hot-formed like solid metal.

In the thermostatic group of new laminated meta Chace No. 6650 warrants mention. This is a new bimeta introduced about 1942, which has exceptionally hig thermal activity (about 30 to 40 per cent more than that previous bimetals) and high electrical resistivity. It recommended for use within a temperature range of −3 to 500 F and, for uniform temperature range and the sa weight, is capable of 63 per cent more work. Anoth bimetal, Chace No. 6850, has 30 to 40 per cent great

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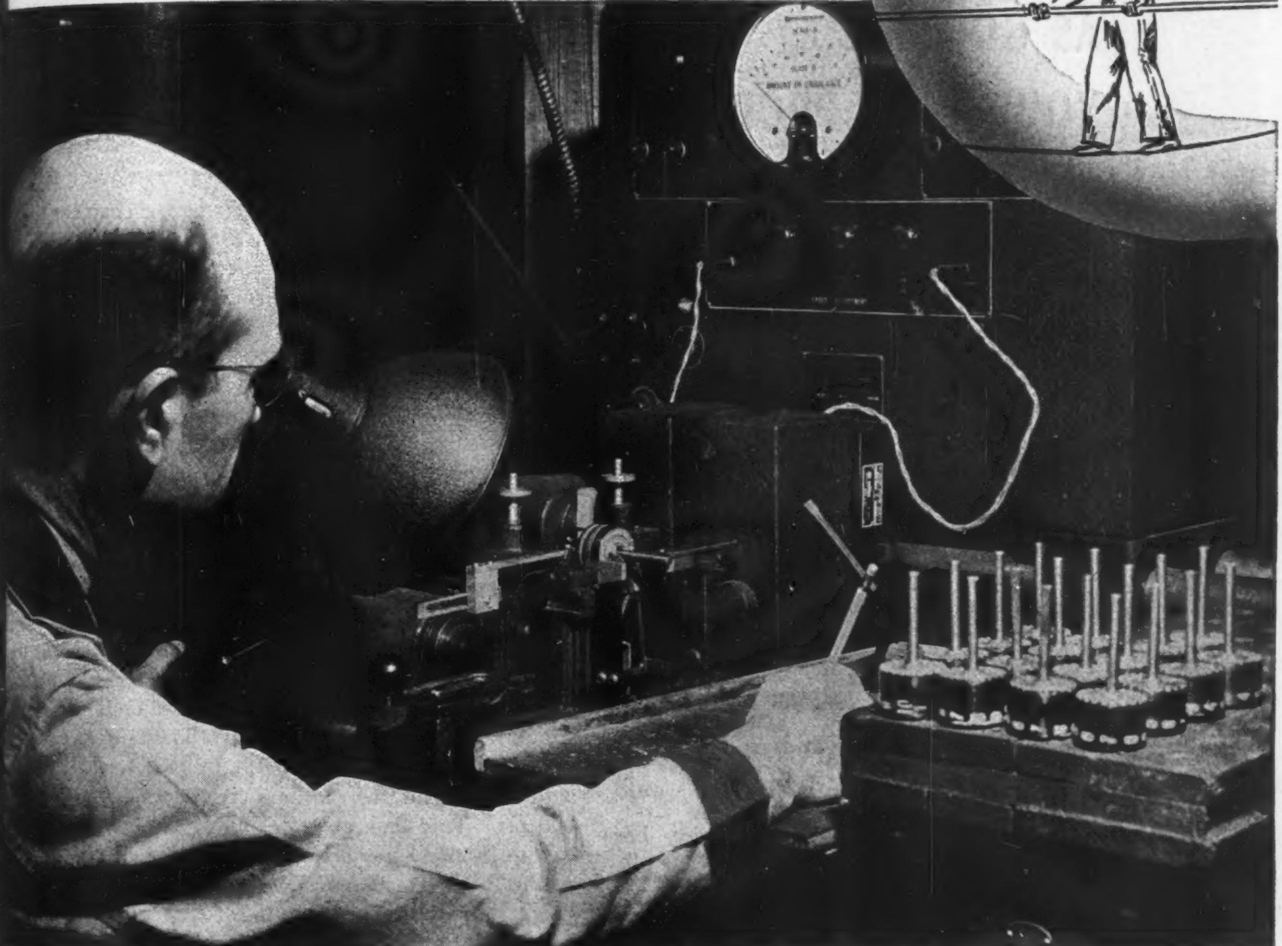

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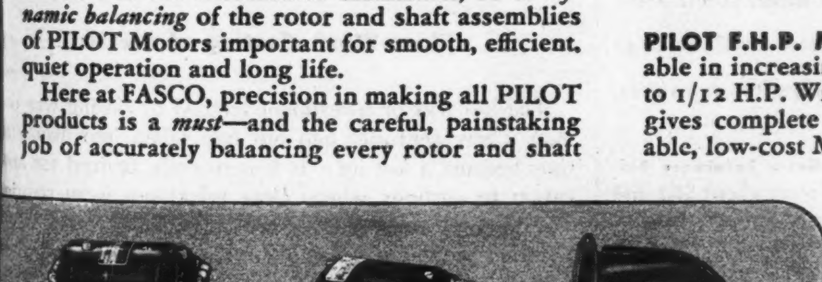

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electrical resistivity than previous bimetals. This m rial is recommended for −100 to 500 F range. Also veloped in the past few years are the copper-faced silver-faced aluminum and aluminum alloys marketed the general plate division of Metals and Controls C under the trade names of "Alcuplate" and "Alsilpl Chief advantages are low specific gravity combined w good conductivity, the latter applying especially to h frequencies.

High-Nickel Alloys

A nickel alloy introduced in 1936, "Z" nickel posse the corrosion-resistant and heat-resistant characteristics commercially pure nickel, but is capable of responding heat treatment and showing exceptionally high tens strength. This alloy contains about 98 per cent nick and its tensile strength ranges from 90,000 to 200,000 p depending upon the amount of cold-working. By he treating the cold-worked material, this can be raised to much as 250,000 psi. The material considerably excee monel in strength, in corrosion resistance it is inferior f certain types of exposure but superior for others.

Another high-nickel alloy, introduced in 1935, "K" monel is a development from the original 67-28 per ce nickel-copper alloy marketed for many years under t tradename of "Monel". The new alloy resulted from th discovery that the addition of a small proportion of alu minum rendered the earlier alloy responsive to heat trea ment. "K" monel consists chiefly of 66 per cent nick 29 per cent copper, and 2.75 per cent aluminum. Tensi strength ranges from 90,000 to 165,000 psi, dependi upon the extent of cold working; by heat treating the col worked material this can be increased to as much as 20 000 psi. This alloy possesses all of the exceptional corr sion-resistant characteristics of the original monel; it a retains both its strength and corrosion resistance at e vated temperatures. At very low temperatures it shows increase in both tensile strength and ductility. It is no magnetic down to very low temperatures, the Curie poi being −150 F or lower, depending upon the conditio and heat treatment.

"Lost-Wax" Casting of Metals

The lost-wax or investment method of casting was com mon a few centuries ago but had fallen into disuse a thus became a lost art. It was recently revived for appl cation to castings where close tolerances were require The method consists basically of molding a wax patte for each individual casting, forming around this a plas cast of some refractory material, heating the mold th formed to flow the wax out after this cast has set and usi this mold for the molten metal. The process has to b repeated for each piece since the cast mold must be d stroyed to remove the casting.

The advantage of this method is its greater accura it permits a higher degree of precision than is possible w any other method of casting except the die or permane mold types. It is claimed that, with small castings, d mensions can be held to within 0.002-in. One of the o standing applications of the process has been in the ca ing of airplane supercharger turbine buckets, which

volved use of an alloy with a melting point of about F. In *Fig.* 6 is a cluster of these buckets cast from lium, an alloy of chromium, cobalt and molybdenum.

Indium

In 1924 the price of indium was around $3800 per pound. Cost has been brought down to about $72 troy pound for 99 per cent purity, thus opening commercial possibilities for the metal. The development of metal is so recent and the price is still so high that its possibilities have not yet been fully explored. One of first uses was in dental casting alloys where small percentages were found to improve corrosion resistance, hardness, and strength. Another application was found the use of fractional percentages to improve wear resistance and corrosion resistance of copper-lead and cadmium lead bearing metals. The most recent application is rather unique plating process used for extending the of bearings.

The pure metal is very soft, has a very low melting point, and is highly corrosion-resistant. It is a fair conductor of electricity, about 20 per cent of that of copper and has an exceptionally high coefficient of thermal expansion, being about twice that of copper.

Lithium

This is the lightest of the metals and is one of the elements which, although known and used for years the form of salts, was not produced as a metal until first world war when a German company used a fractional percentage in an aluminum-zinc alloy. Since then it been used on a larger scale as a hardener in lead-base bearing alloys. Within the past ten years or so, the commercial production of lithium has been started in the United States. Current chief use of metallic lithium is in master alloys and in compounds made from the metal. The master alloys are used in metallurgy because of the exceptionally high affinity of lithium for gases and nonmetallic impurities.

One of the outstanding characteristics of metallic lithium is its readiness to combine with other elements but this quality renders it unsuitable for engineering applications in the pure state. As an alloying element, lithium has tendency to harden and strengthen the matrix in low melting-point metals, especially aluminum and lead. a result of its pronounced tendency to form intermetallic compounds with many other metals, high additions lithium often result in embrittlement of the alloy. Th despite the intriguing fact that lithium weighs only a li more than half as much as water, it does not offer prom as the base metal of an ultralightweight alloy. However it has been found exceptionally valuable in producing high conductivity copper, where it removes both oxygen and hydrogen; only a trace of the lithium itself is left in the copper.

From the viewpoint of the design engineer, lithium of chief interest as providing a means of eliminating m of the defects usually encountered in castings of ma types of metal. Another feature of lithium is its exce tional transparency to X rays, which pass through it li visible light through glass.


Deep hardening molybdenum
steels meet requirements on
jobs involving heavy sections.

Transition Briefs

AS THE FIRST step in a long-term program, the Warner & Swasey Co. is entering the textile field with the production of a knitting machine and a gill box for use in the woolen industry. The company is also studying possibilities in several other fields as protection against the extreme fluctuations peculiar to the machine tool industry which it has served exclusively. As machinery engineers and builders, the company will confine its activities to capital goods and equipment.

CENTRIFUGE SEPARATORS will head the list of peacetime production for Columbia Machine Works Inc., Brooklyn subsidiary of Maguire Industries Inc. Utilizing centrifugally-cast stainless-steel bowls, the separators will be the first in which all parts coming in contact with the product are of stainless.

MAJOR APPLIANCES for homes are expected to begin rolling off the lines of the Westinghouse Electric Corp. in considerable volume in October and November. These include home freezers, clothes dryers and electronic precipitators for air cleaning.

RUBBER INDUSTRY will have employment levels lower than for peak war production but substantially greater than before the war, according to the B. F. Goodrich Co. The industry's goal is 66 million tires in 1946 compared to 50 million in 1940, the last peacetime year. Even when natural rubber becomes plentiful again, s thetics will continue to be produced both for military curity and for low-cost raw materials to broaden mark

EXPANSION PROGRAM of the Trane Co. will m than double its present manufacturing facilities to pe the fabrication of heating and air-conditioning units on assembly-line basis. It will also provide greater facili for production of refrigeration and special heat-trans equipment.

MILITARY FLAME THROWERS are being employ as cultivators to burn out weeds growing between r of young sugar cane in the South, indicating the adaptab ity of much war equipment to peacetime use.

PRODUCTION of 1,400,000 home radio receivers a 450,000 electric refrigerators in the first full year of po war operation has been set by the Crosley Corp. If nece sary the company says it can build 5,000,000 radio se annually.

PLANTS of Square D Co. devoted to the manufactu of electrical distribution and control equipment alrea are virtually converted to normal peacetime operation.

LONGEST continuous production line in the world being built by the Philco Corp. The plant will conta 300,000 square feet of floor space, will cost more than million dollars and will provide eight parallel convey lines for high-speed manufacture of radios and radi phonographs.

Permanent because locked in the material.

May be molded in, or installed later for repair or replacement purposes.

Removable by drilling without disturbing the parent material.

The heart of the Rosán Locking System is the locking ring. Its serrations are broached into the parent material and prevent turning or loosening under vibration or torque.

Rosán Inserts and Studs are easily installed, can be easily removed. They do away with the need for oversize replacements, and so effect great savings in parts inventory, in addition to the savings in parts salvaged.

Leading aircraft companies have adopted the Rosan Locking System. The automotive industry and others are also recognizing the advantages of this revolutionary method of fastening.

Write or wire for full information.

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BUSINESS AND SALES BRIEFS

AMONG other elections recently announced by Celanese Corp. of America is that of H. C. Van Brederode as vice president of Celanese Co. Inc., a wholly owned subsidiary. Mr. Van Brederode previously had been sales manager of the fabric division of Celanese Corp. of America.

♦

James V. Winkler has been added to the Los Angeles staff of The Dow Chemical Co. and will serve as development engineer for magnesium on the West Coast. Connected with the company for four years, Mr. Winkler previously was in charge of experimental engineering at Dow's magnesium fabrication laboratory in Bay City, Mich.

♦

Promotion of W. L. O'Brien to manager of the Stainless Steel Division of Jessop Steel Co., Washington, Pa., has been made known recently. Formerly district manager in Indianapolis, Mr. O'Brien now will make his headquarters in Washington, Pa.

♦

With headquarters at Detroit, Walter H. Bodle has been named assistant to the merchandise sales manager of Square D Co. Ernest R. Walton will succeed him in the management of the company's manufacturing and assembly plant at Seattle, Wash.

♦

Establishment of offices in the Cleveland Trust Bank building, Painesville, O., has been announced by Industrial Hydraulics Corp., a newly formed organization. W. T. "Ted" Stephens is president and chief engineer and W. B. "Mac" McClelland vice president and sales manager. Products designed by the company will be manufactured by Jacobs Aircraft Engine Co. of Pottstown, Pa.

♦

Well Equipment Mfg. Corp. of Houston, Tex., has been named exclusive representative for Chiksan Co. of Brea, Calif., and will handle the distribution of Chiksan ball-bearing swivels in Texas, Oklahoma, Kansas and portions of Mississippi, Arkansas and New Mexico.

♦

Located in the Rice building, 10 High St., Boston, a new sales office has been opened by Latrobe Electric Steel Co. to cover the territory of eastern Massachusetts, Rhode Island, New Hampshire and Maine. Robert S. Rose has been appointed district sales manager of the new office.

♦

Recently announced is the appointment of Diesel Equipment Co., 308 South Second St., Memphis, Tenn., as a distributor for Briggs Clarifier Co. of Washington, D. C. and Bethesda, Md. Jointly owned and managed by Worthington Brown and William F. Fay, the newly appointed distributor will cover western Tennessee, northeastern Arkansas, and por-

tions of southeastern Missouri, southern Illinois, southern Indiana and southern Kentucky. Principal trading centers in this area are Nashville and Memphis, Tenn.; Evansville, Ind. and Paducah, Ky.

♦

Appointment of Maurice C. Libert as manager of the San Francisco office, 870 O'Farrell St., has been made by the New Departure division of General Motors Corp. Mr. Libert has been sales engineer in the Detroit office of this division for seventeen years.

♦

In order to meet the demand for its new products, Rustless Iron & Steel Corp. has announced a building program of ... projects, among which are the relocation and improvement of present hot-rolling facilities to produce a greater variety of sizes of stainless steel rods, and the re-arrangement and enlargement of the cold-rolled shape mills.

♦

A branch office has been opened in the Penobscot building, Detroit, to cover the Michigan, southern Ontario, and northern Ohio territory of Moore Products Co., Philadelphia. J. ... Gambrill has been placed in charge of sales and service for the company's industrial instruments and pneumatic computing gages.

♦

Election of N. J. Clarke as senior vice president has been announced by Republic Steel Corp. Succeeding him as vice president in charge of sales is J. M. Schlendorf, who formerly had been assistant vice president in charge of sales.

♦

Vascoloy-Ramet Corp. of North Chicago, Ill., has moved the Detroit branch office to new quarters at 512 Book building in order to provide more room and a more central downtown location. A. R. Conti will continue to be in charge of sales and service in the Detroit district. Also maintained at this address is the branch office of Fansteel Metallurgical Corp., an affiliate company.

♦

Change of name and location has been announced by Aircraft Parts Development Corp. of Summit, N. J. Henceforth the company will be known as Hungerford Research Corp. and will be located in its new laboratory building in Murray Hill, N. J. In addition to covering product and process development in all fields of industry, the company will continue to specialize in the application of powder metals and plastics to mechanical and electrical products.

♦

To meet increasing needs for prompt service on alloy and stainless steels, The Carpenter Steel Co. of Reading, Pa., has moved its Indianapolis warehouse from 633 Fulton St. to new and larger quarters at 1618 West Washington St. K. L. Crichman, southwestern manager, has been placed in charge of the new warehouse.

♦

According to a recent announcement, Wm. E. Hoard has been appointed area sales manager for the San Francisco area of Western Gear Works and its associate, the Pacific Gear & Tool Works. Prior to his appointment Mr. Hoard had been assistant to the sales manager of Western Gear Works' three West Coast plants, with headquarters in Seattle.

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PROGRESSIVE field engineers, backed by a greatly expanded staff of design and application engineers selected from the resistance welding industry for their breadth of experience and "results", will be glad to help you simplify and speed up your assembly and welding operations.

PROGRESSIVE projection-welding is one of the simplest methods there is to attach one part to another—brackets to larger pieces, forgings to stampings, etc., etc.

Welding dies are simple, hold studs to close tolerances for position. Just drop the parts in place, press a button, and the parts are attached FOR LIFE.

In the example illustrated above, use of standard PROGRESSIVE Press Welders and PROGRESSIVE-ENGINEERED set-up, a number of customary operations are eliminated and yet a BETTER PRODUCT is turned out.

The exact equipment needed for an operation like this depends of course on production quantity. The particular installation shown is being used for high production.

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NEW MACHINES—

And the Companies Behind Them

Communication

Plant broadcasting system, Operadio Mfg. Co., St. Charles, Il
Portable "Handie-Talkie" sets, John Meck Industries Inc., Plymouth, Ind.

Dairy

Corrosion-resistant scale for weighing butter prints, Toledo Scale Co., Toledo, O.
Empty case washer, Girton Mfg. Co., Millville, Pa.

Diesel

*Marine diesel, Joshua Hendy Iron Works, Sunnyvale, Calif.

Excavating

High pressure portable rock duster, Mine Safety Appliances Co., Pittsburgh.
Shovel-crane-dragline, Koehring Co., Milwaukee.
Full-circle, one-man-operated power shovel, Byers Machine Co., Ravenna, O.
Crusher, Nordberg Mfg. Co., Milwaukee.

Food

Wrapping machine, Package Machinery Co., Springfield, Mass.
Jaw-type heat sealer, Pack-Rite Machines, Milwaukee 2.
Electronic jar inspector, General Electric Co., Schenectady, N. Y.
Rotary heat sealer, Codie-Kay Co., Los Angeles 15.

Industrial

Metal disintegrater, Elon Corp., Detroit 2.
Washing machine, Industrial Washing Machine Corp., New Brunswick, N. J.
Portable-type parts cleaning machine, Park Chemical Co., Detroit, 4.
Etching marker, Nagel Bros., Chicago Heights, Ill.
Spray booths and dust-collecting equipment, Metallizing Engineering Co., Long Island City 1, N. Y.
Power screw driver, Torque Tools Ltd., Toronto, Canada.

Laboratory

Self-contained oven, Industrial Oven Engineering Co., Cleveland, 2.

Materials Handling

Wheel-type tractor, Oliver Corp., Cleveland.
Tractor-mounted crane, Henry Lohse Co. Inc., Newark, N. J.
Tractor shovel, M. P. McCaffrey Inc., Los Angeles.
Oscillating-trough conveyor, Link-Belt Co., Chicago.

Medical

Contact and cavity X-ray unit, North American Philips Co. Inc., New York, 17.

Metalworking

Rotary surface grinder, Hanchett Mfg. Co., Big Rapids, Mich.
Extra heavy-duty pneumatic die cushions, Dayton Rogers Mfg. Co., Minneapolis, 7.
Pneumatic drills, The Aro Equipment Corp., Bryan, O.
Vertical centrifugal casting machine, The Centrifugal Casting Machine Co., Tulsa, Okla.

Testing

*Stiffness gage, Taber Instrument Corp., North Tonawanda, N. Y.
Fatigue testing machine, Southwark Div., The Baldwin Locomotive Works, Philadelphia 42.
Tire cord fatigue tester, Ferry Machine Co., Kent, O.
Checker for crankshaft bearings, Anderson Mfg. Co., Rockford, Ill.

Textile

Double twister, Atwood Div., Farrel-Birmingham Co. Inc., Stonington, Conn.

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*Illustrated on Pages 158-159.